Review and Analysis of the Inter-Laboratory Study (ILS) on Upholstered Furniture Composite Mock-Ups

Report Prepared For
Alliance for the Polyurethanes Industry (API)
1300 Wilson Boulevard
Arlington, VA 22209
(703) 741-5656

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Arthur F. Grand, Ph. D.
Grand Fire Consulting
595 Concord Road
Fletcher, NC 28732-9735
(828) 687-0109
agrand@grandfireconsulting.com

and

Neil R. Ullman, P.E.
Ullman Associates
4 Sarazen Court
Florham Park, NJ 07932-2714
Tel: 973-822-3327
Fax: 973-822-3327
Neil1@Ullman.net

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The descriptions of the test specimens and the results presented herein are true and correct to the best of our knowledge and within the bounds of normal scientific methods and techniques. The Inter-Laboratory Study (ILS) was performed in accordance with a protocol that has not undergone any kind of standardization process, formal peer review or validation as of the date of this report.

Further, the results obtained from this test protocol and presented herein constitute a relative rating of performance of composite constructions under the test conditions outlined and are not intended to reflect hazards presented by these or any other composite constructions under actual fire conditions.

ABSTRACT

An Inter-laboratory Study (ILS) was conducted on a small open flame furniture test method, using seven different material combinations and twelve laboratories. The objective of conducting the ILS was to develop a statistical assessment of the test protocol, including repeatability and reproducibility. In addition, comparisons were made of the laboratory-scale results to those from large- and full-scale testing on four of the composites.

The test protocol, based on the British Standard BS 5852 with the "source 1" igniter, involved the testing of laboratory mock-ups that included actual upholstery fabrics and foams, with batting and/or interliner as appropriate. The igniter flame, about the size of a match, candle or butane lighter, was applied for 20 seconds. The progress of the resultant ignition, if any, and continued fire involvement of the specimen was monitored by the mass of the test rig. Mass loss over time was the primary measurement, with mass loss rate and time to a particular mass loss designated as the "test results." Mass loss rate (MLR) of any given material is proportional to heat release rate (HRR), as described in the full report, in accordance with the relationship MLR*Hc = HRR, where Hc is effective heat of combustion. Heat release rate is often used for estimations of potential fire hazard (e.g., see references in the report to the books by Krasny, et al., and Babrauskas and Grayson, the CBUF study and the CFAST and HAZARD I computer models).

The U. S. Consumer Product Safety Commission (CPSC) and the California Bureau of Home Furnishings and Thermal Insulation (CBHFTI) have both expressed interest in a small open flame (SOF) test method for upholstered furniture composites. This ILS was designed, in part, to provide a statistical assessment of the laboratory protocol for use by these regulatory entities.

The seven composite specimens included three types of polyurethane foams, three fabrics (including a fire-retardant treated fabric), two polyester battings, and an interliner, in various combinations. Statistical analyses were developed for the average mass loss rate over the increment from 20 to 40 g mass loss (designated $MLR_{20/40}$), and the time to a mass loss of 10 g (designated t_{10}).

Some of the conclusions developed from the results of this study are as follows:

1) All labs successfully completed the evaluation of the composite specimens in accordance with the test protocol, and submitted results in the manner requested.
2) The within-laboratory "repeatability" of the results and the inter-laboratory "reproducibility" were computed.
3) The coefficients of variation (CV) for repeatability for the $MLR_{20/40}$ values ranged from six percent to 22 percent of the average mass loss rates. The CVs for the t_{10} values ranged from four percent to ten percent.
4) The CV's for reproducibility ranged from eight percent to 44 percent.

5) One composition neither ignited nor lost any mass in any of the tests conducted. Although this could not be dealt with in the statistical treatment (because there was "no result"), this clearly represented a composition that would not ignite under these test conditions. The other end of the range of compositions was represented by specimens that ignited and burned readily.
6) Large scale results (full-size cushion mock-ups) on four of the compositions were quantitatively comparable to the laboratory scale results using the calculation of $MLR_{20/40}$.
7) Full scale results (upholstered chairs), on the same four compositions, were qualitatively similar to the laboratory scale (i.e., producing the same rank order) by comparison of HRR-time patterns to MLR results.
8) The quantitative measurement of mass loss, and subsequent calculation of mass loss rate, which were accomplished without substantial problems and within reasonable levels of consistency, have the potential for use in a regulatory specification.

A series of recommendations are proposed by the authors to address future improvements in the test protocol. Based on the seven composite constructions evaluated in this study, suggestions are also made for possible future testing in the event this protocol is pursued as a regulatory specification.

PROJECT SUMMARY

This report includes the results of an Inter-laboratory Study (ILS) on a small open flame furniture test method and comparison of the "small scale" test results to large- and full-scale testing of identical composite specimens. All of these experiments were conducted independently by the laboratories, but were organized and facilitated by the Alliance for the Polyurethane Industry (API). The test protocol, based on the British Standard BS 5852 with the "source 1" igniter, involved the testing of laboratory furniture composite mock-ups that included actual upholstery fabrics and foams, with batting and interliner as appropriate. The igniter flame, about the size of a match, candle or butane lighter, was applied for 20 seconds. The progress of the resultant ignition, if any, and continued fire involvement of the specimen was monitored by the weight (mass) of the test rig.

Mass loss of the specimen was the primary measurement, with mass loss rate and time to a particular mass loss designated as the "test results." Mass loss rate (MLR) is proportional to heat release rate (HRR), as described in the full report, in accordance with the relationship MLR*Hc = HRR, where Hc is effective heat of combustion (although Hc would not be expected to be constant over the entire duration of the burning of a composite product, it does not change the fact that MLR and HRR are related). Heat release rate is often used for estimations of potential fire hazard (e.g., see references in the report to the books by Krasny, et al., and Babrauskas and Grayson; the CBUF study and the CFAST and HAZARD I computer models).

The U. S. Consumer Product Safety Commission (CPSC) and the California Bureau of Home Furnishings and Thermal Insulation (CBHFTI) have both expressed interest in a small open flame (SOF) test method for upholstered furniture composites. No such method currently exists in any North American standard; whereas standards exist for open flame exposure of certain furniture components, for smoldering cigarette ignition of mock-up composites and for larger open flame exposure of full-size furniture items. The intent of exposing a laboratory furniture mock-up to a small open flame is to evaluate the resistance of the composite to ignition and spread of flame, rather than to estimate the performance of the composite based on the testing of one or more components. The development of such a test method recognizes the complex nature of the burning of composite specimens, whether on a laboratory- or larger-scale test specimen.

The ILS was conducted with twelve laboratories on seven composite specimens. Each specimen contained an upholstery fabric and a flexible polyurethane foam; four composites included polyester batting, two of those contained an interliner (FR barrier) as well. The fire performance of the specimens ranged from one that did not ignite in any of the tests to ones that ignited and spread flame rapidly. An attempt was made to include composites that would "test" the ability of the protocol to differentiate among fire performance characteristics of various types of furniture composites.

The primary objectives of the complete study (ILS and larger scale testing) included the development of a statistical assessment (repeatability and reproducibility) of the

laboratory protocol and assessment of the potential of such a test method to be suitable for regulatory use. The comparison of the laboratory results to those produced by the "large scale" (Cal. TB 133 cushion mock-up) and "full scale" (actual furniture item) experiments should be important to those evaluating the regulatory potential.

Brief descriptions of the components of the composite specimens are presented in Table S-1 (Table 2 from the report).

Table S-1. Combinations of Components for ILS Tests

Series	Fabric[1]	Foam[2]	Batting[3]	Interliner[4]
1	"Selected" fabric	New Cal. 117	None	None
2	"Selected" fabric	New Cal. 117	Conventional	None
3	"Selected" fabric	New Cal. 117	New Cal 117	None
4	"Selected" fabric	New Cal. 117	Conventional	Commercial FR
5	"Selected" fabric	BS 5852, crib 5	None	None
6	FR back-coated	Non FR	None	None
7	Heavy polyolefin	New Cal. 117	Conventional	Commercial FR

Notes (more detailed descriptions are in the body of the report):

1) "Selected fabric" was a 64/36 blend of rayon/polyester with no back coating, 13.8 oz./linear yd.; the "heavy polyolefin" was a 72 percent polyolefin/28 percent polyester, with a latex back coating, 20.1 oz./linear yard; the "FR back-coated" was the "selected fabric" treated to comply with BS 5852, source 1.
2) The "New Cal. 117" polyurethane foam was compliant with the Feb. 2002 draft revision of the Cal. 117 standard; the "BS 5852, crib 5" polyurethane foam was compliant with the specifications in the crib 5 procedure in BS 5852. All foams were 1.7-1.8 pcf density with 25 % ILD between 27 and 29 lbs.
3) "Conventional" batting was a common, commercial polyester batting; while "New Cal 117" was compliant with the Feb. 2002 draft revision of the Cal. 117 standard. These battings were 1 in. thick and 1 oz./sq. ft.
4) The "commercial FR" interliner (or barrier fabric) was "Furn 85," from Freudenberg Nonwovens.

In the laboratories, the mass of the specimen was recorded as a function of time for the duration of the test. Subsequently the "mass loss" and the "mass loss rate" were calculated for various increments. The "test results" selected for the statistical analyses reported herein were as follows: 1) the average mass loss rate (in g/s) over the increment from 20 to 40 g mass loss, designated $MLR_{20/40}$; and 2) the time (seconds) to a mass loss of 10 g, designated t_{10}.

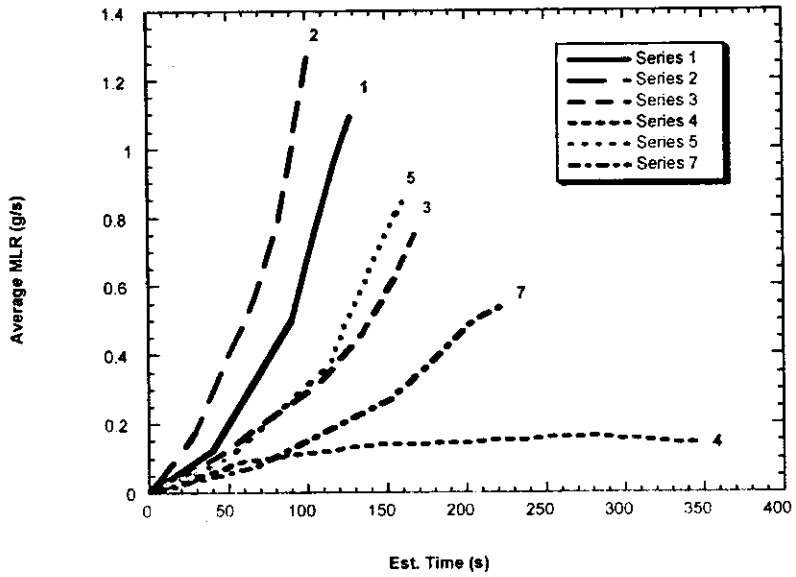


Figure S-1. Overall average small scale MLRs for all ILS labs

Figure S-1 (Fig. 4 from the report) is an illustration of the curves of mass loss rate (MLR) vs. time for the six specimens that had some mass loss during the course of the test (i.e., all except "Series 6" which did not sustain ignition and lost no mass in any of the tests conducted). The times used to develop these plots were back-calculated from the average MLR values, as described in the report.

Each specimen was tested three times in each laboratory, producing a total of 252 sets of data from the ILS. A complete statistical assessment of the results ($MLR_{20/40}$ and t_{10}) of these laboratory tests is included in the report. While it is difficult to summarize the statistical results, the following can be said about the ILS:

1) All labs successfully completed the testing of the composite specimens in accordance with the test protocol, and submitted results as requested.
2) The within-laboratory "repeatability" of the results and the inter-laboratory "reproducibility" were dependant both on the nature of the various specimens and the ability of each of the laboratories to conduct the tests.
3) The repeatability of the results of testing certain specimens was excellent, with coefficients of variation (CV) for the $MLR_{20/40}$ value on the order of 10 percent or less of the average value. Other specimens were not as good, ranging as high as 22 percent. The CV values were not proportional to the average MLRs.
4) The CV's for reproducibility of the $MLR_{20/40}$ values ranged from about 10 percent to over 40 percent. Again, the CV values were not proportional to the average MLRs.

Summaries of the average test results and of the precision statistics for $MLR_{20/40}$ and t_{10} are shown below as Tables S-2 and S-3, respectively (Tables 6 and 8 from the report). The small "r" refers to repeatability (within lab) and the capital "R" to reproducibility (between labs).

Table S-2. Summaries of precision statistics for $MLR_{20/40}$ (all values in g/s, except CV which is percent)

Series	Avg. MLR	s_r	s_R	r	R	CV_r	CV_R
1	0.86	0.07	0.09	0.18	0.25	7.7	10.2
2	0.90	0.11	0.19	0.32	0.53	12.6	21.1
3	0.52	0.10	0.23	0.28	0.65	19.4	44.7
4	0.16	0.01	0.03	0.03	0.09	6.3	19.6
5	0.64	0.14	0.20	0.40	0.56	22.3	30.8
7	0.44	0.05	0.08	0.13	0.22	10.4	18.2

Table S-3. Summaries of precision statistics for t_{10} (all values in s, except CV which is percent)

Series	Avg. t_{10}	s_r	s_R	r	R	CV_r	CV_R
1	83.4	5.7	9.0	15.9	25.2	6.8	10.8
2	63.0	6.3	13.6	17.8	38.1	10.1	21.6
3	96.1	5.8	13.1	16.1	36.7	6.0	13.6
4	114.9	5.6	8.9	15.8	25.1	4.9	7.8
5	105.3	8.1	16.3	22.6	45.6	7.6	15.5
7	135.1	5.8	12.1	16.1	34.0	4.3	9.0

Abbreviations used in these tables are as follows:

s_r and s_R – standard deviation for repeatability and for reproducibility, respectively;
r and R – repeatability and reproducibility "intervals," respectively; and
CV_r and CV_R – coefficients of variation (expressed as a percentage) for repeatability and for reproducibility, respectively.

Graphical representation of the more important of these statistics (s_r and s_R) for $MLR_{20/40}$ and for t_{10}, respectively, are shown in Figures S-2 and S-3 (Figures 5 and 6 from the text).

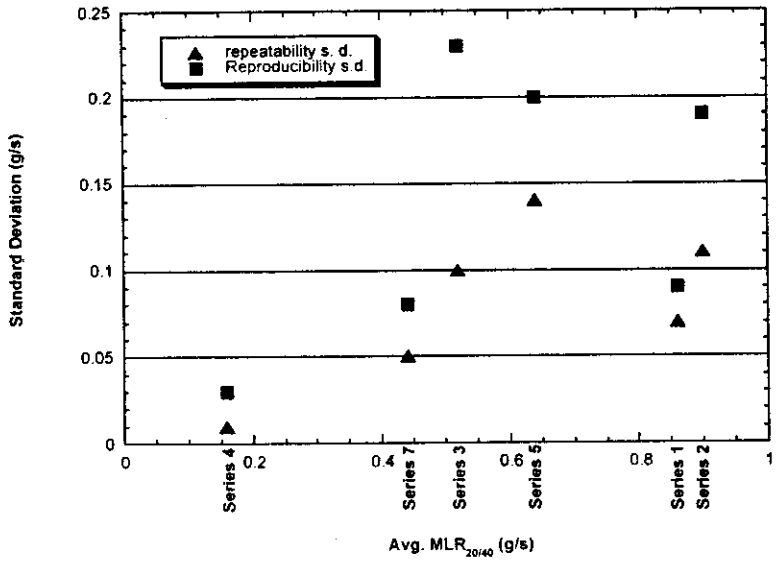


Figure S-2. Repeatability and reproducibility standard deviations as a function of average $MLR_{20/40}$.

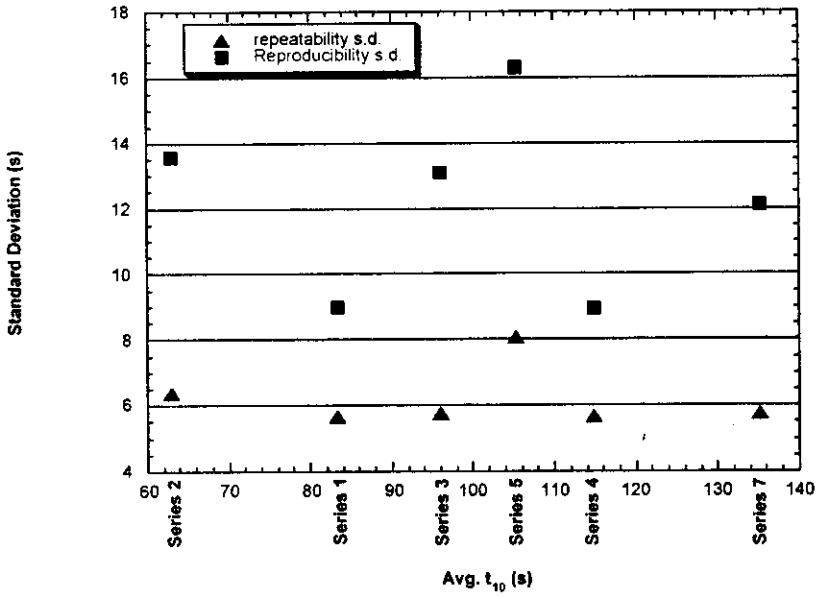


Figure S-3. Repeatability and reproducibility standard deviations as a function of average level of t_{10}.

The statistical treatments performed on other fire tests (e.g., ASTM E1354, the "cone calorimeter"; ASTM E1537, same as CA TB 133; and ASTM E1352, a smoldering cigarette test) were each performed "differently" from the way in which the statistical

analysis was performed for this ILS (which involved more laboratories, generally more specimens, with a more detailed analysis of the results). Also, the "results" of one fire test are generally not directly comparable to the results of another fire test because of the complex character of ignition and flame spread. On the other hand, when fire scientists discuss the results of fire experiments, a difference of ±10 percent between two specimens is generally considered to be not out of the ordinary. Much higher variations than this have been reported for accepted fire tests. Thus, the variability of the measurements in this ILS are within the general range anticipated for a fire test method.

Seven composite specimens were evaluated in accordance with this test method. One of the compositions ("Series 6," with the FR treatment of the fabric) did not ignite or burn and therefore lost no mass. Although all laboratories, in triplicate experiments, obtained the same "result" (i.e., zero mass loss), there was no result from a statistical point of view. Therefore, the data from this specimen have not been included in any calculations.

The composition with the lowest measured average mass loss rate was Series 4, which included an interliner (FR barrier) between the fabric and the batting/foam. As shown in Table S-2, this composition produced an average $MLR_{20/40}$ of 0.16 g/s. This measurement may be expressed as a "95 percent confidence interval" (±2 standard deviations) as follows: 0.16±0.02 g/s. This is excellent repeatability for a fire test method. For this composite, even the reproducibility was reasonably good ($2*s_R = 0.06$ g/s).

The other specimens, other than Series 6 and Series 4, all ignited and burned. Some of them burned rapidly and others more slowly. These ILS MLR results, within the 95 percent confidence interval, do not permit statistically-significant differentiation of the five composites from one another (see Figure S-4, Figure 15 from the report). While the apparent "rank order" of the average $MLR_{20/40}$ values is complemented by the results of the large- and full-scale results to be discussed, any regulatory requirement should take into account the variability in results that could be achieved by different laboratories.

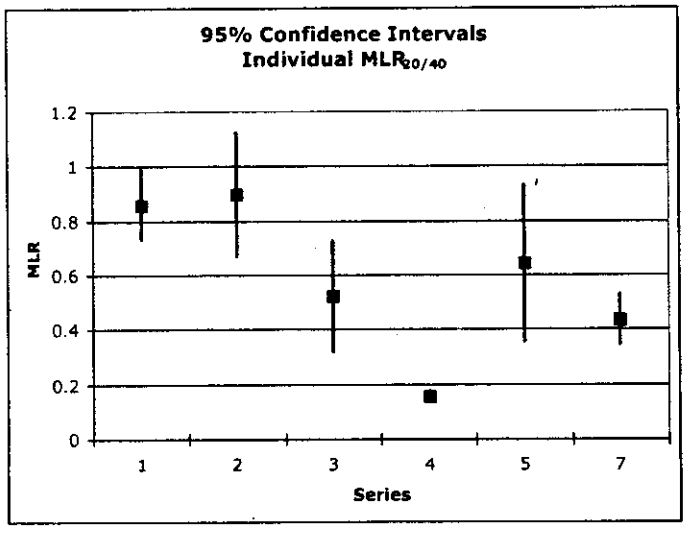


Figure S-4. Average $MLR_{20/40}$ values for each Series, with ± 2 s_r

Large scale (LS) and full scale (FS) fire tests were also conducted during the course of this program, for comparison to the ILS small scale (SS) tests. The LS specimen configuration consisted of Cal TB 133-size cushions positioned in that test's mock-up frame. The FS configuration consisted of full size upholstered lounge-style chairs (photographs of each of these are in the report). In both cases, the components used were the same as for the same "series" in the ILS and the ignition burner and application time were the same as for the ILS. The four compositions selected for the comparison testing were as follows:

Series 2 – Fabric, conventional batting, foam
Series 3 – Fabric, new Cal 117 batting, foam
Series 4 – Fabric, interliner, conventional batting, foam
Series 7 – Heavy polyolefin fabric, interliner, conventional batting, foam

Comparisons of the results among the SS, LS and FS tests were accomplished in two ways. Mass measurements were obtained from the LS tests for comparison to the SS results, and are shown in Figure S-5 (Fig. 12 from the report). In addition, heat release rate (HRR) results from both the LS and FS tests were obtained for comparison to one another and to aid in an estimation of "rank order" of these specimens with respect to fire performance and potential fire hazard. These HRR plots are shown in Figures S-6 and S-7 (Figs. 13 and 14, respectively, from the report).

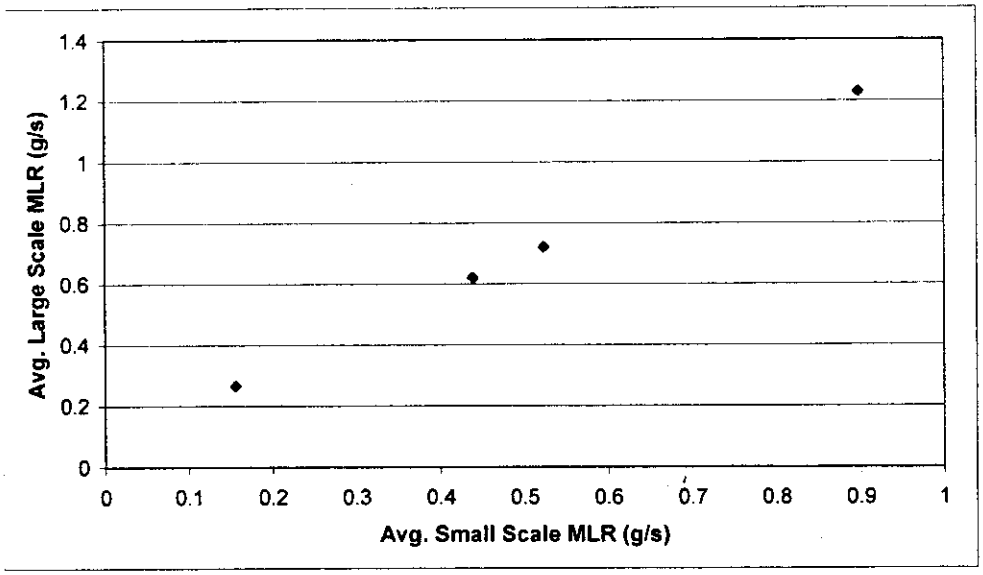


Figure S-5. Average large scale $MLR_{20/40}$ results vs. average small scale $MLR_{20/40}$ results

The results shown in Fig. S-5 represent a correlation of these particular MLR results between the average SS and the average LS tests. Although this should not be interpreted as a general correlation of the results of different size specimens, the relationship is encouraging with respect to the development of a legitimate comparison of the small scale protocol with larger scale fire behavior.

The HRR-time plots (Figs. S-6 and S-7) contain results of certain large scale (LS) and full scale (FS) experiments. The plots were selected to be typical of those available in an effort to represent the results of the study (HRR plots for all LS and FS test runs are contained in Appendix C).

Interpretation of the HRR results relies on the following presumptions regarding HRR-time relationships: lower HRR (especially at the peak) and longer time to reach any given HRR (or the peak HRR) generally correspond to better fire performance and a lower fire hazard. When both time and HRR are relatively higher or lower for a given composition, the case is even stronger, within the limits of repeatability of the test. HRR and time to reach some given HRR are analogous to the laboratory scale calculations of $MLR_{20/40}$ and t_{10}.

It is apparent from the large scale HRR results in Fig. S-6 (which are supported by a non-statistical estimation of variability of these results as discussed in the report) that the "ranking" of the four materials evaluated in large scale tests is as follows: from poorer fire performance to better, Series 2, Series 3, Series 7 and Series 4 (which clearly had the best results of these four compositions).

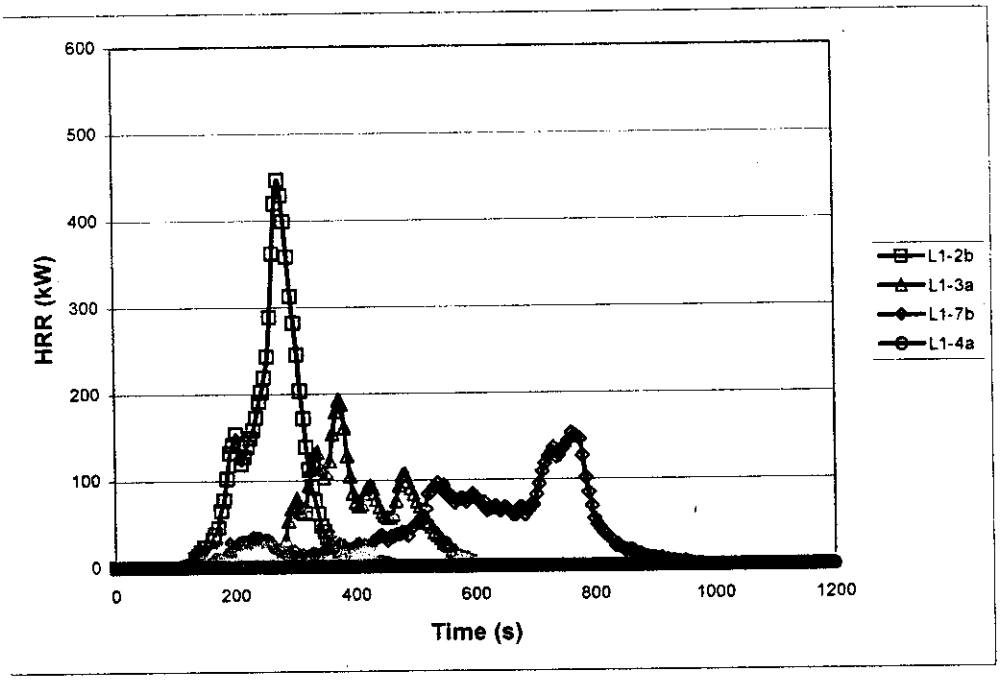


Figure S-6. Selected plots of large scale test HRR results on different constructions (Series 2, 3, 4 and 7)

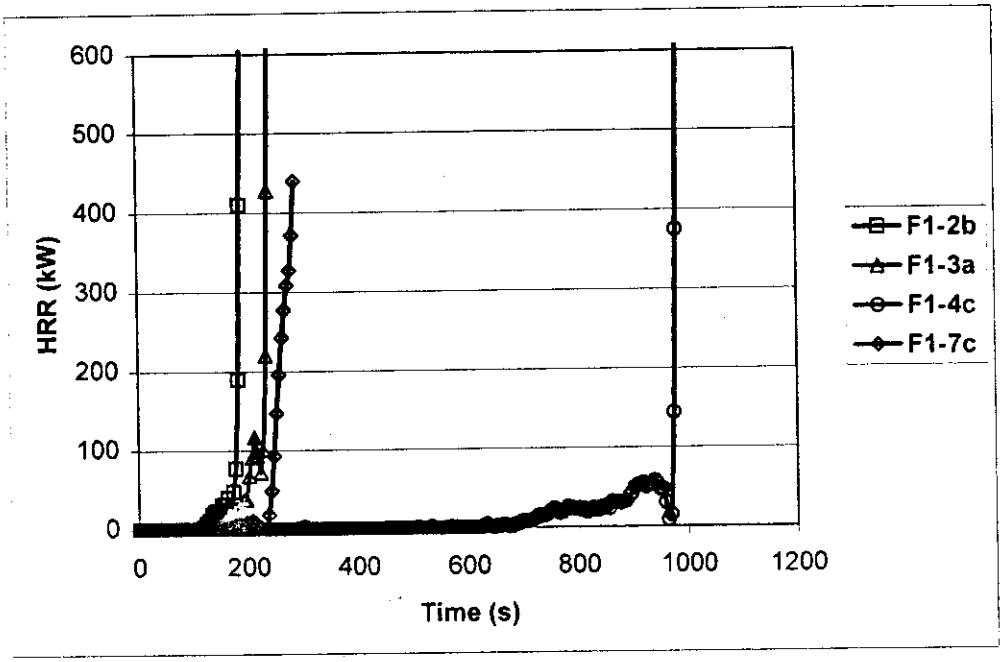


Figure S-7. Selected plots of full scale test HRR results on different constructions (Series 2, 3, 4 and 7)

The mass loss readings in the early part of the full scale (FS) tests were considered to be less reliable than those for the SS or LS experiments, due to differences in the load cells for the heavier furniture specimens. Therefore, only the HRR curves were used for comparison of the FS tests to the LS tests.

As illustrated in Figure S-7, all four of the specimens tested in the full scale (upholstered chair) tests eventually burned and approached or reached the equivalent of flashover in a "standard" fire test room (i.e., 1000 kW in a room 10 ft. x 12 ft. x 8 ft. high). While this result was not a surprise for three of the compositions, the results of the "Series 4" specimens were not anticipated. As discussed in the report, possible differences in the final integrity of the interliner (barrier fabric) may have caused the Series 4 specimens to eventually progress to full burning. In any event, the difference between the range of times to a major increase in HRR for Series 2, 3 and 7 (Figure S-7) and that for the Series 4 tests is substantial. The three compositions began to burn vigorously at approximately 150 to 250 s (around 4 minutes or less); while the Series 4 specimens did not start burning rapidly until about 900 to over 1000 s (15 minutes or more). This substantial increase in potential "time to escape" for the Series 4 compositions reinforces the results of the laboratory and large scale tests – that this composition was substantially different from the others.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions derived from this study may be summarized as follows:

1. The ILS on a small open flame (SOF) exposure of upholstered furniture mock-ups was completed successfully. Thus, twelve, very different laboratories were able to conduct the test procedure and to derive comparable results from the testing.
2. The statistical evaluation of the ILS results was more detailed and more in keeping with the precepts of ASTM E691 than probably any other fire test previously examined. The results of the statistical assessment ran the range from excellent "repeatability" (within laboratory) for some of the compositions to a lower order of repeatability for some of the other compositions (e.g., they ranged from a coefficient of variation of less than 10 percent of the average value to greater than 20 percent).
3. The reproducibility (between laboratories) encompassed a wide range (from less than 10 percent of the average value to more than 40 percent for one composition). Assessments of these variations and some rationale for the poorer reproducibility results were presented.
4. A major finding from the statistical assessment was that the Series 4 composite (with the "selected" fabric, an interliner, batting and foam), which ignited and burned at a slow rate, had a lower average mass loss rate ($MLR_{20/40}$) than the five other compositions that ignited, even taking into account the range in the average MLR values at the 95 percent confidence level.
5. One composition ("Series 6," which contained an FR-treated fabric) neither ignited nor lost any mass under this test protocol in any of the labs in triplicate tests. Although not dealt with in the statistical assessment (because there was "no result"), this composition represented an obviously good outcome for this test protocol. Thus, nearly the full range of possible results was demonstrated by these ILS tests, from a specimen that would not ignite to specimens that ignited and burned rapidly.
6. Based on the results presented in this report, component testing alone may not be suitable for predicting the fire performance of composite products. This statement is supported by the following observations: a) the use of a BS 5852 crib 5-compliant foam (Series 5) in place of a California T. B. 117 foam (Series 1) did not substantially improve the fire performance of the composite specimen; b) ignition of a heavy fabric was sufficient to cause an interliner to eventually break through (Series 7 in the LS and FS tests); and c) the fire performance characteristics of the fabrics were of critical importance to the fire performance of the composite specimens in this test protocol (based on observations of all specimens).
7. The recording of mass loss and subsequent calculation of mass loss rate, which were accomplished without major problems and with some level of consistency, have the potential for use in a regulatory specification.
8. Large scale (California T. B. 133-size cushions in a mock-up) and full scale (actual upholstered furniture) specimens were tested, using the same ignition source as for the ILS. The large scale results were quantitatively comparable to

the laboratory scale measurements, using the calculation of $MLR_{20/40}$; and the full scale results were qualitatively similar, using comparison of HRR, to the rank order of lab- and large-scale results. It is recommended that additional tests be performed to supplement those conducted in this program.

9. Mass loss rate is an accurately measured parameter that is relevant to fire hazard assessment of burning furniture items. The relative errors in the results, both in the laboratory scale and in larger scale experiments, must be taken into account if this method is considered for regulatory action.

Recommendations were developed by the authors for changes in the test protocol, based on the results obtained during the ILS; and for additional tests that could be conducted to supplement those described in this report. These recommendations are offered to help improve the scientific validity of the test and, possibly, to also improve the repeatability and reproducibility of the method. A brief list of these recommendations is shown below:

Recommendations for improvements in the test protocol include the following areas:

1. Installation of batting
2. Identification of components
3. Limitation on airflow near the specimen
4. Specifications for the end of a test
5. Decision on rounding of values
6. Establishment of the "initial mass"
7. Clarification of the start time

More consistent attention to these operational points should reduce the level of variation among future test results.

Recommendations for additional laboratory experiments include the following:

1. Additional specimens with moderate to low mass loss rates
2. Differentiation among specimens with moderate to high mass loss rates
3. Tests including batting
4. Calibration techniques or use of a "standard" specimen
5. Evaluation of a variety of different fabrics
6. Further large scale or full scale tests

INTRODUCTION

An inter-laboratory study (ILS) was undertaken on a new laboratory fire test method for composite furniture formulations. The results of the ILS are contained in this report. The test method, based on the British Standard BS5852[1], has been under consideration by the California Bureau of Home Furnishings and Thermal Insulation (CBHFTI) and by the U. S. Consumer Product Safety Commission (CPSC). In a previous laboratory study[2], the important parameters of the test protocol and the diversity of possible material combinations were described.

Prior to the ILS, numerous tests were conducted to establish the operating parameters for the method. A report covering these tests was issued (ref. 2), which includes specimen preparation, the nature of the technical output of the test and commentary on the analysis and interpretation of the test output.

The test method is based on the response of laboratory-scale upholstered furniture mock-ups to a small open flame (SOF) ignition source about the size of a burning match (the Source 1 igniter described in the British Standard BS5852). In the studies conducted for the ILS, seven composite specimens were prepared and tested by 12 laboratories. The specimens consisted of various combinations of fabrics, foams, battings and an interliner (or fire-retardant barrier). The quantitative output of the test is mass loss of the composite specimen as a function of time. Several options regarding a final "test result" (or results) were considered over the course of this study, including average mass loss rate over a selected portion of the test and time to a specific mass loss. Other methods of treatment of the data are discussed in the report.

No standard flammability test method in North America currently provides for the evaluation of ignition and early fire development of composite furniture mock-ups by a small open-flame. Flammability tests exist for the assessment of individual furniture components, such as fabrics and foams (e.g., California Technical Bulletin 117); for the exposure of furniture composites to cigarettes (e.g., ASTM E1352) and for the evaluation of full-size furniture or cushion mock-ups to larger open flame sources (e.g., CA TB 133/ASTM E1537).

OBJECTIVE

The objective of conducting the ILS was to develop data for a statistical evaluation of the within-laboratory repeatability and inter-laboratory reproducibility of the test protocol. Additional objectives gleaned from the ILS, and of the supplemental testing of large- and full-scale composite specimens, included the following: 1) develop information for CBHFTI and CPSC related to a possible regulatory test method; 2) generate comparisons and/or correlations of the ILS (small scale) results with results from the large- and full-scale tests; 3) evaluate the test protocol and provide information to CBHFTI and CPSC as they develop a method for future use.

APPROACH

The test protocol for the ILS is contained in Appendix A ("ILS Test Documents and Protocol"), which includes all of the notes, letters and instructions sent to the laboratories prior to the start of the laboratory testing. Sending detailed instructions to the laboratories is standard procedure for an ILS. All twelve of the laboratories completed the testing. An abbreviated listing of the participants is presented in Table 1.

Table 1. Laboratories Participating in the ILS

two independent test laboratories –
California Bureau of Home Furnishings and Thermal Insulation
Omega Point Laboratories, Inc.
two fiber manufacturing representatives –
Cotton Inc.
DuPont – Spruance Plant
three polyurethane chemical manufacturers –
BASF Corporation
Bayer Polymers
Huntsman
five polyurethane foam producers –
Carpenter Company
Hickory Springs
Foamex International
Future Foam, Inc.
North Carolina Foam Industries

The main features of the test procedure may be summarized as follows:

1) The specimen consists of a laboratory mock-up of a selected fabric/foam composite, including batting and/or interliner, as would be used in an actual item of upholstered furniture. Other similar-size flammability test methods deal only with the evaluation of individual components.
2) A small flame, similar in size to a match, candle or butane cigarette/fireplace lighter, is used to simulate a potentially common source of ignition in homes. This is in contrast to the larger open-flame ignition source for California TB 133 that is intended to simulate a larger accidental or intentional ignition.
3) The igniter is held at the juncture of the mock-up "seat" and "back" cushions for 20 seconds.
4) The quantitative measurement of mass loss of the composite is used to track the progress of the burning. This is a more quantitative, scientific measurement than char length, flame height, or time to an observation. Calculations performed with the mass loss data may be used to estimate "mass burning rate" of the composite

specimen, which is related to heat release rate (but without the additional equipment required for measurement of heat release).

5) The test may be conducted under a standard-size laboratory exhaust hood, as long as the interior of the hood meets certain fire resistance and air flow criteria.

The output of the test is mass as a function of time. Laboratories were instructed to compute mass loss directly from the output data, and average "mass loss rate" over selected increments.

The laboratories were asked to complete a summary table consisting of times (interpolated if necessary) to 10, 20, 30 and 40 g mass lost (and to higher mass loss values, if the experiments could be continued safely). In addition, the laboratories reported average mass loss rates for each of the 10-g increments (i.e., between 10 and 20 g, between 20 and 30 g, etc.). Additional test results, as described below, were computed from the information provided by the labs.

TEST SPECIMENS

Test data were obtained on the seven composite specimens described in Table 2. Each specimen type ("Series") was run in triplicate by each laboratory.

Table 2. Combinations of Components for ILS Tests

Series	Fabric	Foam	Batting	Interliner
1	"Selected" fabric[1]	New Cal. 117[4]	none	none
2	"Selected" fabric[1]	New Cal. 117[4]	Conventional[7]	none
3	"Selected" fabric[1]	New Cal. 117[4]	New Cal 117[8]	none
4	"Selected" fabric[1]	New Cal. 117[4]	Conventional[7]	Commercial FR[9]
5	"Selected" fabric[1]	BS 5852, crib 5[5]	none	none
6	FR back-coated[2]	Non FR[6]	none	none
7	Heavy polyolefin[3]	New Cal. 117[4]	Conventional[7]	Commercial FR[9]

Notes to Table 2:

1. "Selected fabric" was a 64 percent rayon/36 percent polyester blend, 13.8 oz./linear yard (54 in. width), not back-coated.
2. "FR back-coated" fabric was the same as the "selected" fabric, with an FR back coating (for compliance with BS 5852 source 1); the weight of the back-coating was approximately 4.5 oz./linear yd. (54 in. width).
3. "Heavy polyolefin" fabric was a 72 percent polyolefin/28 percent polyester material, 20.1 oz./linear yard (54 in. width), which included a latex back coating.

4. "New Cal. 117" polyurethane foam was compliant with the Feb. 2002 draft revision of the Cal. 117 standard[4]. This foam had the following properties: density 1.7 pcf, 25 % ILD 27 lbs.
5. "BS 5852, crib 5" polyurethane foam was compliant with the specifications in the crib 5 procedure of BS 5852[1]. This foam had the following properties: density 1.8 pcf, 25 % ILD 29 lbs.
6. "Non FR" polyurethane foam contained no fire retardant additives. This foam had the following properties: density 1.8 pcf, 25 % ILD 28 lbs.
7. "Conventional" polyester batting was not compliant with any particular fire test protocol; it was 1 in. thick and 1 oz./sq. ft.
8. "New Cal 117" polyester batting was compliant with the Feb. 2002 draft revision of the Cal. 117 standard[4]; it was 1 in. thick, 1 oz./sq. ft. and about 10 percent Basofil® fiber by weight.
9. "Commercial FR" interliner was Furn85, available from Freudenberg Nonwovens

The range and types of composite specimens evaluated in these studies were based on results of previous laboratory testing (refs. 2 and 3), on the nature of materials currently in commercial use for upholstered furniture, and on the perceived needs of regulatory authorities relative to this test method. Following were the rationale for selection of the compositions listed in Table 2:

1. A wide range of fire performance was sought, from specimens that probably would not ignite (i.e., Series 6) to ones that would likely ignite and burn readily (i.e., Series 1 and 2).
2. Additional specimens were selected that might ignite and burn at different "rates" in comparison to one another, especially ones with slow to intermediate fire involvement (i.e., bracketing the likely results of Series 6, on the one hand, and Series 1 and 2, on the other hand). Such results could not be definitively predicted from the previous laboratory tests.
3. Some comparisons of non-FR and FR fabrics and foams were sought. In particular, a back-coated FR treatment on a typical fabric might not ignite; therefore, a non-FR foam under such a fabric might not be a problem. Also, it was anticipated that a more highly fire-retarded foam (BS5852, crib 5) would probably not perform substantially better in this composite test than a California 117 foam.
4. Comparison of composite specimens with and without batting was sought, as was comparison of specimens with and without an interliner. It was also of interest to determine whether or not there was a substantial difference between "conventional" batting and the new Cal 117 batting.
5. Thus, the specimen-by-specimen comparison of the seven composite specimens may be presented as follows: Series 1 – ordinary upholstery fabric on Cal 117 foam, a "normal" composition; Series 2 – same as Series 1, but with conventional batting; Series 3 – same as Series 2, but with Cal 117 batting, in place of conventional; Series 4 – same as Series 2, but with an interliner (or barrier); Series 5 – same as Series 1, but with a more highly fire retarded foam; Series 6 –

same base fabric as Series 1 through 5, but FR backcoated; Series 7 – same as Series 4 (with batting and interliner), but with a "heavy polyolefin" fabric, instead of that used in Series 1 through 5.

INITIAL PRECISION CALCULATIONS AND TYPICAL RESULTS

A complete test involved the burning of a single mock-up. The start of the test was upon application of the igniter onto the specimen. The mass was monitored continuously but recorded at specific time intervals of from 5 to 15 seconds. An initial mass was determined and all subsequent mass values were subtracted from the initial to provide a collection of combustion mass loss values at each time increment. The overall test data therefore consists of a collection of times, mass readings and calculated mass loss values. Mass data during the 20-s application of the igniter were "ignored" (i.e., assumed to be "0" mass loss) because of the discrepancies in mass readings due to holding the igniter in place.

Each laboratory attempted to perform three complete runs on replicate mock-up constructions of each of the seven compositions ("Series"). Each of the seven compositions was evaluated separately. The triplicate tests conducted by each laboratory were under the same test conditions, thus permitting an estimation of the "repeatability" of the method. Since all laboratories tested identical sets of materials, the differences among laboratories permit an estimate of the "reproducibility" of the method.

It was critical to this study to provide information on appropriate ways to summarize the results of these fire tests. Since there were no standard definitions of a test result from this protocol, a number of possibilities were examined. Two calculations were used in these ILS precision estimates, as described below:

1) Mass Loss Rate, the change in mass over a specific time interval; and
2) Time to reach a specific mass loss

Mass loss rate is a quantitative measure of the physical phenomenon of losing mass during combustion. It is related directly to heat release rate (HRR), which is often used for estimations of potential fire hazard (e.g., see references 7, 8, 9 and 10).

Time to reach a specific, low mass loss is analogous to "time to ignition," or time to sustained burning. In this test method, the actual point of ignition cannot be determined with accuracy because the igniter is, itself, a small flame.

After considering numerous options for each of these calculations, the average mass loss rate over the range of mass loss from 20 g to 40 g ($MLR_{20/40}$), and the time to reach 10 g mass loss (t_{10})were selected.

A results summary table was required of all laboratories. This table included times to each 10-g increment throughout the run (i.e., 10, 20, 30 and 40 g minimum, others if obtained). The times were developed from a simple linear interpolation between adjacent data pairs (time-mass loss) and were rounded to the nearest second. The average MLR (mass loss rate) for each of the 10-g increments was also reported. An example of a summary table for a single run (S3-1a) is shown in Table 3:

Table 3. Example of summary table requested from laboratories

Time (s)	ML (g)	MLR (g/s)
0	0	
80	10	0.125
99	20	0.531
112	30	0.793
121	40	1.024
130	50	1.144
138	60	1.213

The two statistics are then computed as follows:

1) The average mass loss rate (MLR) over the 20-40 g ML range ($MLR_{20/40}$) is computed from the interpolated times to 20 g mass loss and 40 g mass loss. In the example given in Table 3, $MLR_{20/40} = 20/(121-99) = 0.909$ g/s.
2) The interpolated time to reach 10 g mass loss (t_{10}) is read directly from the summary table. In the example in Table 3, this $t_{10} = 80$ s. (Note that, in most cases, the time to 10 g mass loss was interpolated from actual readings either side of 10 grams.)

The two calculations, $MLR_{20/40}$ and t_{10}, were conducted "after" the conduct of the tests. No changes in test procedure were required, the calculations were based on the raw data obtained. Other "calculations" could be made from the laboratory data in a similar manner.

Typical measurements of mass vs. time obtained during a test are illustrated in Figure 1 (which depicts a sequence of runs from one laboratory). In Figure 2, mass loss vs. time has been calculated for the same runs and plotted. These single runs were selected to be representative of the kinds of results obtained during this study for the seven specimens, but they do not represent any average or median result.

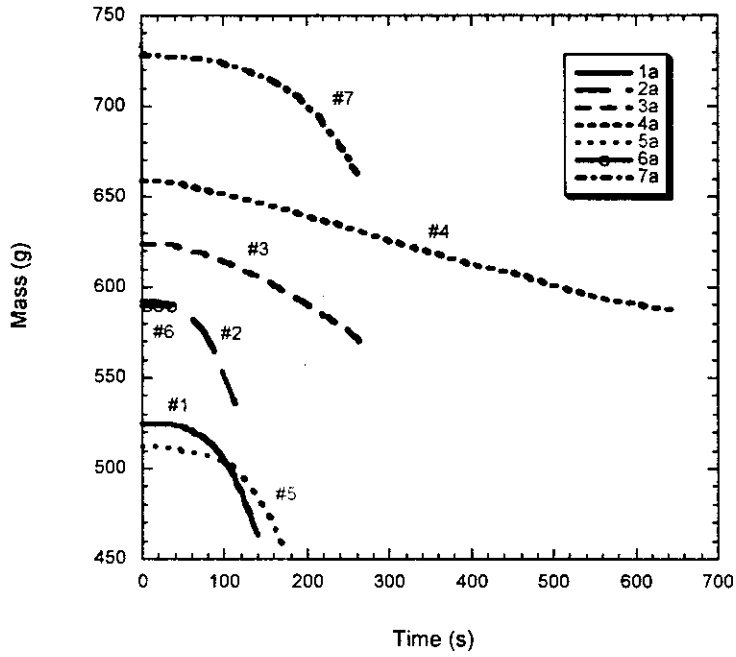


Figure 1. Mass of Seven Specimens During Testing (Example)

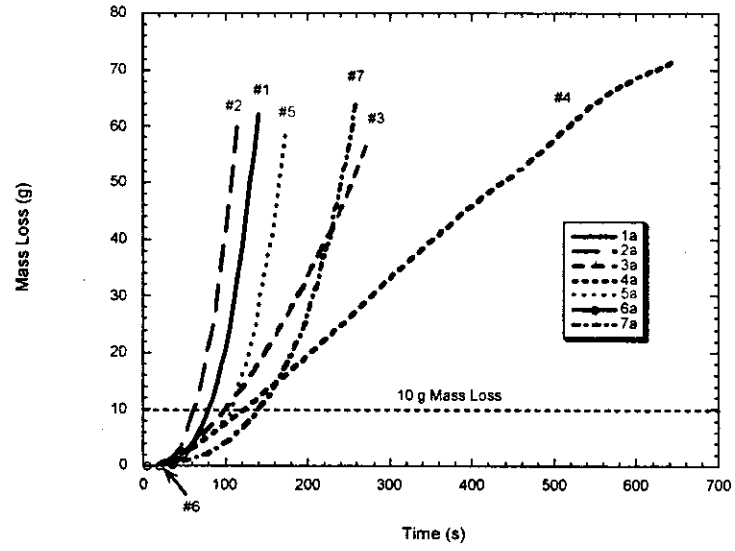


Figure 2. Mass Loss of Seven Specimens During Test (Example)

It is apparent from observation of Figure 1 that each of the specimens had a unique initial mass. For this reason, it is difficult to assess the relative differences among specimens using only mass vs. time. In Fig. 2, on the other hand, the mass loss curves for all specimens "start" at the same point on the graph, so direct comparison of mass loss may be made, and a tentative assessment of rate of change of mass can be inferred. A line has been drawn across the plot in Fig. 2 at 10 g mass loss to illustrate how the times to 10 g ML would be obtained.

The more rapid rate of mass loss of Specimens 1, 2 and 5 are apparent In Figure 2, while the lower MLR of the Series 4 specimen is evident. Series 4 consistently had the lowest MLR of all of the specimens that burned (i.e., all except Series 6 which did not ignite and therefore had no mass loss).

In Figure 3, "mass loss rate" (MLR) is plotted as a function of time for the same examples shown in Figures 1 and 2. Mass loss rate is the rate of change of mass loss vs. time (i.e., the derivative of the ML-time curve). The results in this figure were subjected to a simple "smoothing" routine in order to remove some of the erratic nature of the MLR calculations at each data point (i.e., every 6 seconds). While it is not necessary for this test protocol that MLR be computed for the entire range of ML-time results obtained, curves such as this are valuable as illustrations of the pattern of MLR over time.

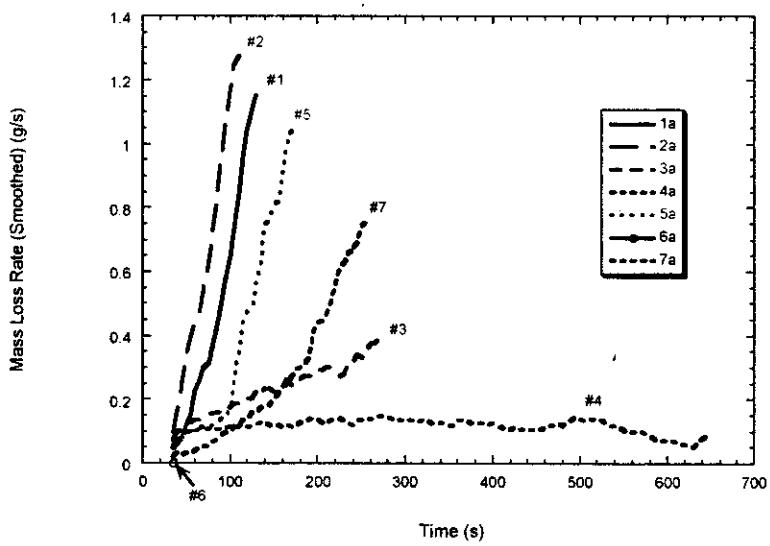


Figure 3. MLR (smoothed) of Seven Specimens (Example)

The data represented by Figures 1 through 3 were from a sequence of runs performed in one laboratory, as an example of typical results obtained, including the calculations and data presentation. In Figure 4, all of the small scale results (i.e., those presented by the laboratories in the format shown in Table 3) were averaged. Because of the nature of the data reporting, the "time" for each of these curves was estimated from the ratio of the ML (g) to the MLR (in g/s) for each mass loss increment. The results shown in this figure represent the overall averages of all of the results submitted.

Comparison of the curves in Figure 4 with those in Figure 3 illustrates an interesting anomaly in the laboratory results. In Figure 3, it is apparent that the specimen representing Series 3 burned more slowly than that for Series 7; whereas in Figure 4, it is the reverse. Further discussion of specimen preparations in the Series 2 (conventional batting) and Series 3 (Cal 117-compliant batting) will be presented later.

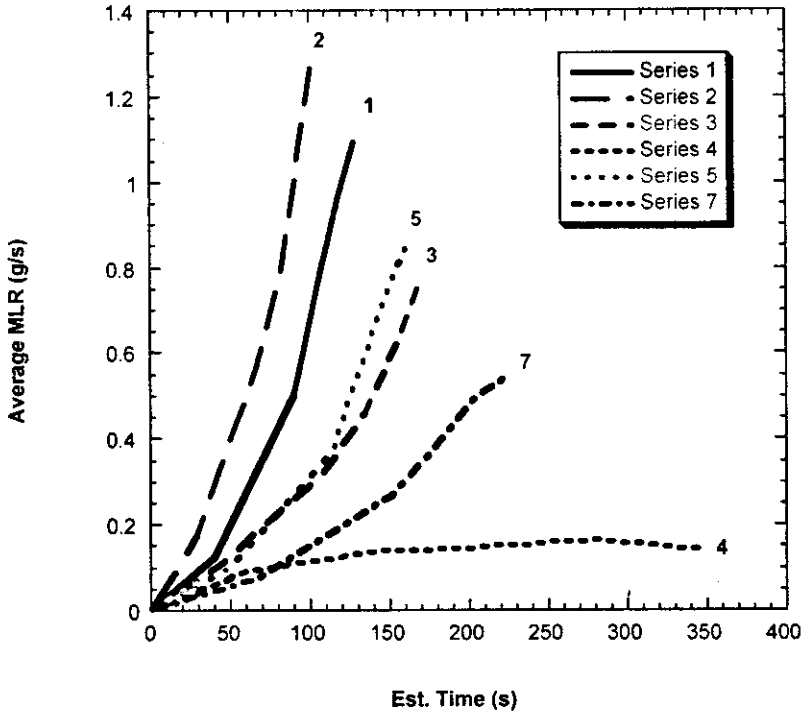


Figure 4. Overall average small scale MLRs for all ILS labs

ILS STATISTICAL RESULTS

Mass Loss Rate ($MLR_{20/40}$)

Each laboratory conducted three tests and, therefore, up to three separate MLRs (20-40 g ML range) were possible for each series (composition). All tests within a given Series were then independently examined.

Table 4 contains the results from each lab for Material Series 1. The three MLRs have been computed, and are listed in columns T1, T2 and T3 (i.e., Test 1, etc.). No results were obtained for Laboratory 5 since all of their tests were terminated prior to reaching 40 g mass loss. The average and standard deviations of the three MLR's are listed for each laboratory.

Table 4. Material series 1, all labs, all tests–$MLR_{20/40}$

Lab	T1	T2	T3	Ave	sd
1	0.87	0.77	0.77	0.803	0.058
2	0.83	0.80	0.83	0.822	0.019
3	0.89	0.87	0.88	0.880	0.014
4	0.91	0.83	0.80	0.847	0.056
5	------	------	-------		
6	0.91	0.83	0.80	0.847	0.056
7	0.74	0.95	0.80	0.831	0.109
8	1.00	1.00	0.83	0.944	0.096
9	1.00	0.95	1.05	1.002	0.050
10	0.70	0.77	0.78	0.752	0.046
11	0.83	1.00	0.91	0.914	0.083
12	0.77	0.91	0.83	0.837	0.070
		Repeatability sd			0.066
		Overall average		0.862	
		sd between averages		0.070	
		Reproducibility sd		0.088	

"Repeatability" is the within-laboratory standard deviation and is calculated by taking the square root of the average of the squares of the individual laboratory standard deviations. Mathematically, this is shown in Equation 1 (which is equation 7 of ASTM E691-99):

$$s_r = \sqrt{\frac{\sum s^2}{p}} \qquad \text{Eqn. 1}$$

where s is standard deviation for any given lab and p is the number of labs.

This calculation is also described as "pooling" the standard deviations. It should be noted that if one of the standard deviations from any of the labs is very large, compared to the

others, that value will have a strong influence on the overall repeatability value. Based on the standard deviations for 11 laboratories, the typical repeatability (or variation) among results in a single lab for Series 1 is 0.066g/s (see Table 4).

The average values for each laboratory are averaged and the overall average of all labs is found (for this series, it is 0.862 g/s, as shown in Table 4). Next, the variation among the laboratories is determined by computing the standard deviation between laboratory averages. For this series the "standard deviation between laboratory averages" (symbolized as $s_{\bar{x}}$) is 0.070g/s.

From the variation within lab (repeatability) and the variation among laboratory averages, the reproducibility standard deviation can be computed. This is the variation that would be expected among individual test results taken from different laboratories. From Equation 8 of ASTM E691-99, the following equations are presented:

$$s_R = \sqrt{(s_{\bar{x}})^2 + \frac{(n-1)}{n}(s_r)^2} = \sqrt{(0.070)^2 + \frac{2}{3}(0.066)^2} = 0.088 \qquad \text{Eqn. 2}$$

where n is the number of repeat results in each laboratory.

Table 5. Averages and standard deviations by lab for $MLR_{20/40}$ (g/s)

	Series 1		Series 2		Series 3		Series 4		Series 5		Series 7	
Lab	ave	sd	ave	sd	ave	sd	ave	sd	ave	sd	ave	sd
1	0.803	0.058	0.822	0.368	0.722	0.089	0.178	0.018	0.684	0.050	0.493	0.085
2	0.822	0.019	0.939	0.052	0.437	0.033	0.131	0.011	0.683	0.035	0.479	0.046
3	0.880	0.014	0.991	0.041	0.301	0.036	0.138	0.004	0.772	0.019	0.433	0.052
4	0.847	0.056	1.072	0.034	0.514	0.034	0.190	0.018	0.763	0.063	0.563	0.040
5			0.851	0.026	1.037	0.064	0.137	0.005	0.713	0.157	0.479	0.047
6	0.847	0.056	0.954	0.045	0.372	0.134	0.121	0.003	0.524	0.096	0.382	0.011
7	0.831	0.109	1.002	0.050	0.720	0.168	0.184	0.010	0.704	0.084	0.450	0.040
8	0.944	0.096	0.968	0.027	0.469	0.174	0.160	0.010	0.665	0.120	0.449	0.054
9	1.002	0.050	0.926	0.067	0.313	0.070	0.129	0.011	0.682	0.013	0.471	0.040
10	0.752	0.046	0.909	0.033	0.594	0.056	0.155	0.003	0.852	0.109	0.412	
11	0.914	0.083	0.417	0.009	0.499	0.151	0.215	0.002	0.300	0.005	0.288	0.002
12	0.837	0.070	0.924	0.025	0.299	0.020	0.136	0.004	0.395	0.417	0.365	0.024
avg.	0.862		0.898		0.523		0.156		0.645		0.439	
sd bet avg.	0.070		0.165		0.218		0.030		0.160		0.071	
s repeat	0.066		0.113		0.102		0.010		0.144		0.045	
s repro	0.088		0.189		0.234		0.031		0.199		0.080	

In Table 5 the averages and standard deviations of each set of results (i.e., three results for each "series" or composition) are listed for each laboratory. Note that lab 5 did not have results for Series 1; that lab 10 had only one test result for Series 7; and, as noted previously, the Series 6 compositions did not ignite, therefore produced no result and are not included in the statistical calculations. The table also contains the overall average ("avg."), the standard deviation between laboratory averages ("sd bet avg."), and the repeatability and reproducibility standard deviations ("s repeat" and "s repro," respectively).

The complete set of results from the ILS are located in Appendix B.

In Table 6, the various precision measures are summarized by Series. The overall average, and the repeatability and reproducibility standard deviations (s_r and s_R, respectively) are included. These three values are the only ones required to describe precision of the test method in accordance with ASTM E691.

Two additional sets of calculations are provided, in accordance with section A21.2.7 of the Form and Style for ASTM Standards. The first pair of values are the "repeatability interval" and the "reproducibility interval," symbolized as "r" and "R," respectively. These are calculated as 2.8 times the respective standard deviations (e.g., the "r" value for Series 1 was calculated to be 0.18g/s). These values are estimates of the maximum difference that might be expected (95% of the time) for two test results conducted under the same conditions. For example, if a "typical" lab repeatedly tested pairs of Series 1 compositions, the difference in $MLR_{20/40}$ should be less than 0.18 g/s 19 times out of 20. Similarly, tests conducted in two different labs would be expected to produce $MLR_{20/40}$ results within 0.25 g/s 95 percent of the time.

Table 6. Summaries of precision statistics for $MLR_{20/40}$ (all values, except CV, in g/s)

Series	Avg. MLR	s_r	s_R	r	R	CV_r	CV_R
1	0.86	0.07	0.09	0.18	0.25	7.7	10.2
2	0.90	0.11	0.19	0.32	0.53	12.6	21.1
3	0.52	0.10	0.23	0.28	0.65	19.4	44.7
4	0.16	0.01	0.03	0.03	0.09	6.3	19.6
5	0.64	0.14	0.20	0.40	0.56	22.3	30.8
7	0.44	0.05	0.08	0.13	0.22	10.4	18.2

The last two columns in Table 6 are the coefficients of variation for repeatability and reproducibility (CV_r and CV_R, respectively). They are the ratios of standard deviation to average MLR, multiplied by 100 to convert to percentage.

Coefficients of variation have been computed for many fire test "parameters" in other fire test methods. Often they are referred to as a "percentage of the mean." In some cases, the CV's have been averaged to produce a single value for a variety of results. Averaging is only appropriate when the CVs are essentially constant across all levels tested. In the case of this test method, it is apparent from the results in Table 6, that the CV's are not constant over the range of average MLRs and a single "percentage of the mean" is not appropriate for these results.

A graphical display, Figure 5, is useful in evaluating the relevance of CV for this test method. In this figure, the repeatability and reproducibility standard deviations are graphed as a function of the average level. It can be seen how the repeatabilities (s_r) and reproducibilities (s_R) of the various MLR's tend to be randomly high or low, except for material 4 which had the lowest $MLR_{20/40}$ and the lowest s_r and s_R values.

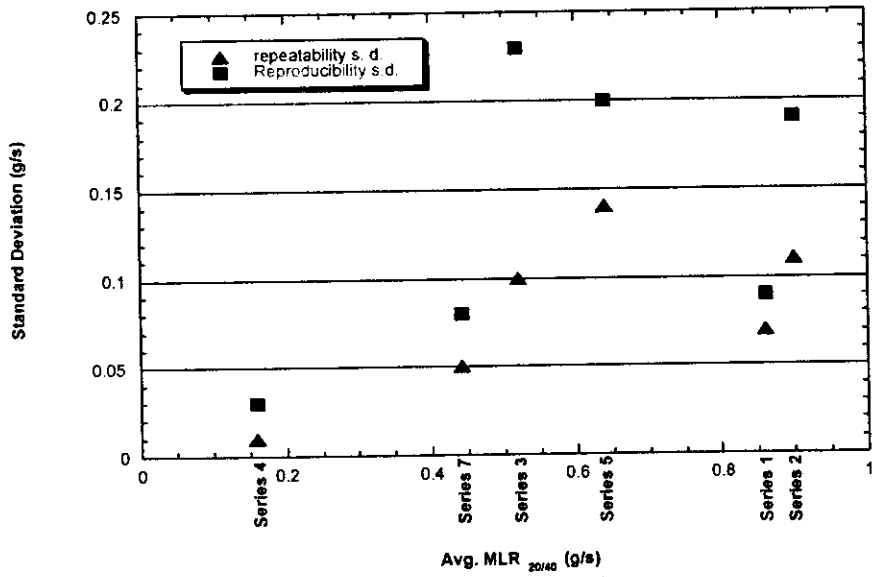


Figure 5. Repeatability and reproducibility standard deviations as a function of average $MLR_{20/40}$.

Time To 10g Mass Loss (t_{10})

The second calculation, or test result, chosen to compare materials is the time to reach 10 grams of mass loss, t_{10}. This is read directly from the summary sheets (interpolated, if necessary, from the raw data).

The times to reach 10 grams of mass loss are summarized in Table 7. This table also contains the averages and standard deviations for each laboratory and each material. All labs ran all tests until at least 10 grams of mass loss, so there are no gaps as experienced with the results in Table 6. The overall repeatabilities and reproducibilities are also shown.

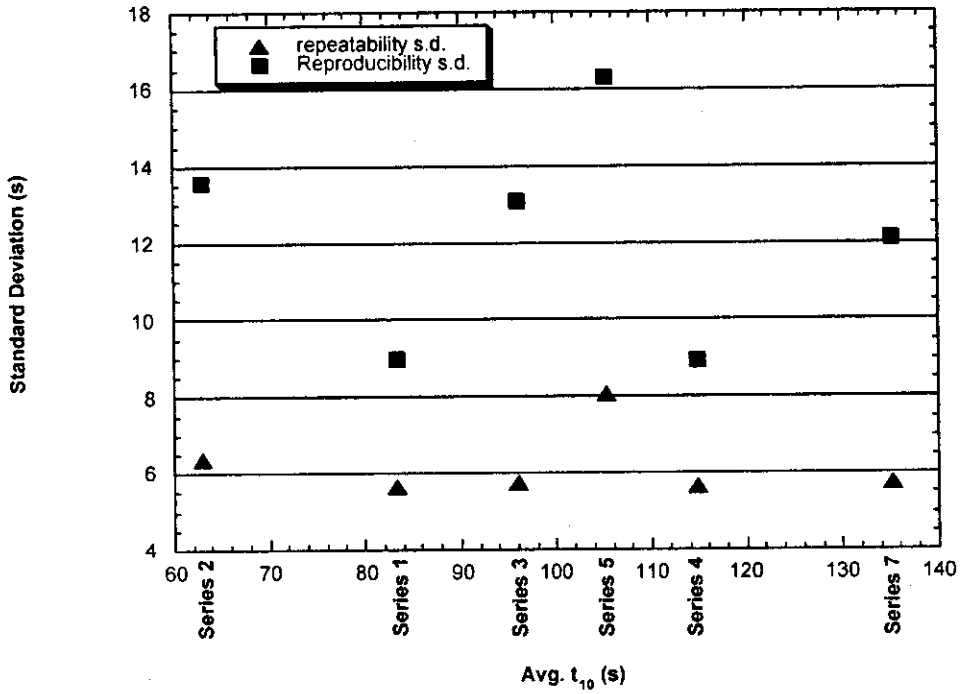


Figure 6. Repeatability and reproducibility standard deviations as a function of average level of t_{10}.

Evaluation of the Statistical Results

A major purpose of this study was to determine consistency of results when this protocol is performed under "constant" conditions in any given laboratory (i.e., the same operator and the same operating conditions) and when performed by different laboratories (involving different operators and more diverse operating conditions).

Two types of statistical comparisons are generally conducted:

1. Variability: Comparing the standard deviation of the laboratory test results with the overall repeatability for all laboratories on the particular series.
2. Average level: Comparing the average of the laboratory test results with the overall average of all laboratories on the series.

Variability

The first concern is whether some test results are significantly different in some way from the other tests on the same material. Each laboratory tested three specimens of each material. If one of these three tests was extremely different in its response, that one test may have a serious influence on the average and standard deviation for the lab. It will increase the standard deviation for the repeatability for that laboratory and possibly cause

the overall repeatability to appear larger. The dilemma, however, is that without an understanding of the cause of the difference, it is unclear whether this type of result might be typical of future tests.

For each material, every laboratory repeatability standard deviation (i.e., the within-lab variation) is compared to the overall repeatability for that material (based on the collection of laboratories). This is found as the ratio of the individual standard deviation to the material repeatability and is symbolized by the letter "k." For example, for Series 1, Lab 1 had a standard deviation of 0.058 and the overall repeatability standard deviation was 0.066, so

$$k = 0.058/0.066 = 0.88.$$

As an approximate rule of thumb, when this value is more than about 2.0, the individual set of tests should be considered potentially unusual (see ASTM E691).

Table 9 contains a complete listing of the k values for each laboratory and each material for the $MLR_{20/40}$ results. It can be seen that two k values (shown in bold) are much larger than the others. These are for Lab 1, Series 2; and Lab 12, Series 5. It is unclear at this time whether or not there was something grossly incorrect or identifiably different with any of those test results. As noted above, those two sets of readings possibly caused the overall repeatability standard deviation to be larger than might otherwise be the case. It also causes the k values for the other laboratories to be smaller than would occur if they were not included.

Table 9. k values for each lab and material series for $MLR_{20/40}$

Series / Lab	1	2	3	4	5	7
1	0.88	**3.26**	0.88	1.82	0.35	1.87
2	0.29	0.46	0.33	1.09	0.24	1.01
3	0.21	0.37	0.36	0.44	0.13	1.15
4	0.85	0.30	0.33	1.81	0.43	0.89
5		0.23	0.63	0.50	1.09	1.04
6	0.85	0.40	1.32	0.35,	0.66	0.24
7	1.66	0.44	1.66	1.04	0.58	0.88
8	1.46	0.24	1.72	1.01	0.83	1.19
9	0.76	0.59	0.69	1.13	0.09	0.88
10	0.70	0.29	0.55	0.27	0.76	
11	1.27	0.08	1.49	0.24	0.04	0.05
12	1.06	0.22	0.20	0.36	**2.89**	0.52

Figure 7 consists of a collection of dot diagrams to illustrate how the k values differ by laboratory. Here it is possible to see if "clustering" occurs which might indicate that some laboratories regularly have low values of k (indicating they are performing with much

less variation than the other labs) or tend to have high values of k (implying they have much larger variation when they repeat the tests). These results will be discussed further under the section on comparing laboratories.

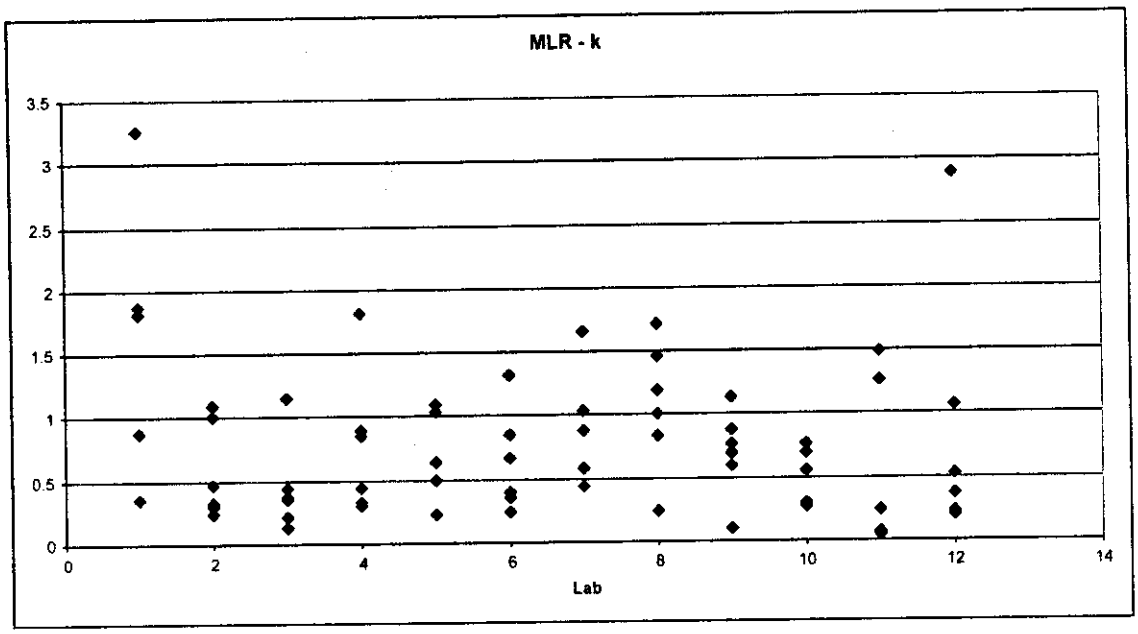


Figure 7. Dot diagrams showing values of k grouped by laboratory.

Average Level

The second concern is how the laboratories compare with one another. This is examined by determining the relative difference in one lab from the overall average. One procedure is to calculate a measure designated "h" which is found as follows:

$$h = (\text{Avg. of lab results} - \text{Avg. of all results}) / (\text{SD of lab averages})$$

Thus, the deviation of the particular lab from the collection of labs is evaluated. Since each material might exhibit a different amount of variation, dividing by the standard deviation among the set of lab averages "standardizes" the differences. This will also permit comparison of the relative differences among the different materials.

For example, $MLR_{20/40}$ results for Series 1 had an overall average of 0.862 and a standard deviation of laboratory averages of 0.070 (see Table 5). Laboratory 1 had an average of 0.803. Thus, the h value for Lab 1 is calculated as follows:

$$h = (0.803 - 0.862)/0.070 = -0.843$$

(Note: this value is slightly different from the result in Table 10 due to rounding errors.)

Table 10. h values for $MLR_{20/40}$ for each laboratory and material

h by lab	1	2	3	4	5	7
1	-0.85	-0.46	0.91	0.73	0.25	0.76
2	-0.57	0.25	-0.40	-0.86	0.24	0.57
3	0.26	0.56	-1.01	-0.61	0.80	-0.08
4	-0.21	1.05	-0.04	1.14	0.74	1.76
5		-0.28	2.35	-0.64	0.43	0.58
6	-0.21	0.34	-0.69	-1.19	-0.75	-0.80
7	-0.44	0.63	0.90	0.94	0.37	0.16
8	1.19	0.43	-0.25	0.15	0.13	0.15
9	2.01	0.17	-0.96	-0.92	0.23	0.46
10	-1.58	0.06	0.32	-0.04	1.29	-0.38
11	0.75	-2.91	-0.11	2.00	-2.15	-2.13
12	-0.35	0.16	-1.02	-0.69	-1.56	-1.05

The h values for each laboratory (1 through 12) are shown in Table 10 and plotted in Figure 8.

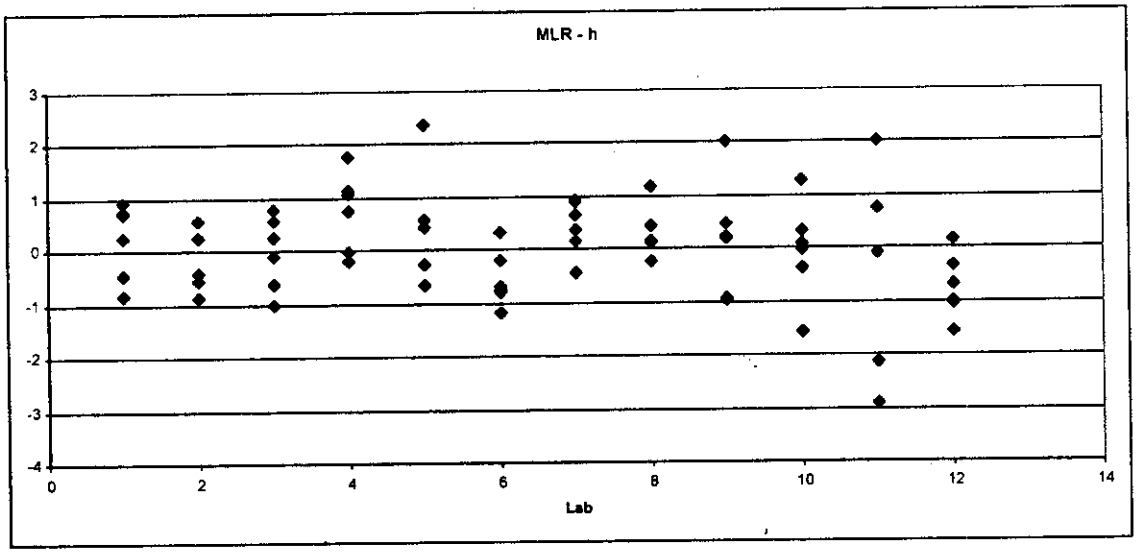


Figure 8. h values for $MLR_{20/40}$ by laboratory

Laboratories with an acceptable random variation in results should have points on both sides of "0," with less than about 1 point in 20 (five percent) outside of ±2. From the results in Fig. 8, it appears that some systematic shifting may be present (i.e., some labs are mainly above zero and others generally below). In addition, several readings are in excess of ±2 (in particular, Lab 11 has three of five readings outside that range).

The second parameter examined, in addition to $MLR_{20/40}$, was time to 10 grams (t_{10}). The k and h values are presented below, in a similar manner as was done for the $MLR_{20/40}$ results.

Table 11. k values for t_{10} by laboratory and material

Lab	1	2	3	4	5	7
1	0.35	**3.03**	0.66	1.60	0.22	1.83
2	0.27	0.00	0.36	1.68	1.18	0.87
3	0.19	0.17	0.45	0.47	0.52	0.20
4	0.20	0.45	0.87	0.98	0.31	0.82
5	0.62	0.40	0.56	0.64	1.80	1.23
6	1.00	0.87	0.92	1.07	**2.14**	0.70
7	1.70	1.14	1.65	0.64	0.68	0.80
8	1.06	0.33	1.46	0.37	0.26	1.66
9	0.37	0.09	0.63	0.47	1.15	0.70
10	1.74	0.12	1.21	1.15	0.70	1.04
11	0.54	0.09	1.60	0.18	0.12	0.27
12	1.70	0.47	0.27	1.33	0.00	0.36

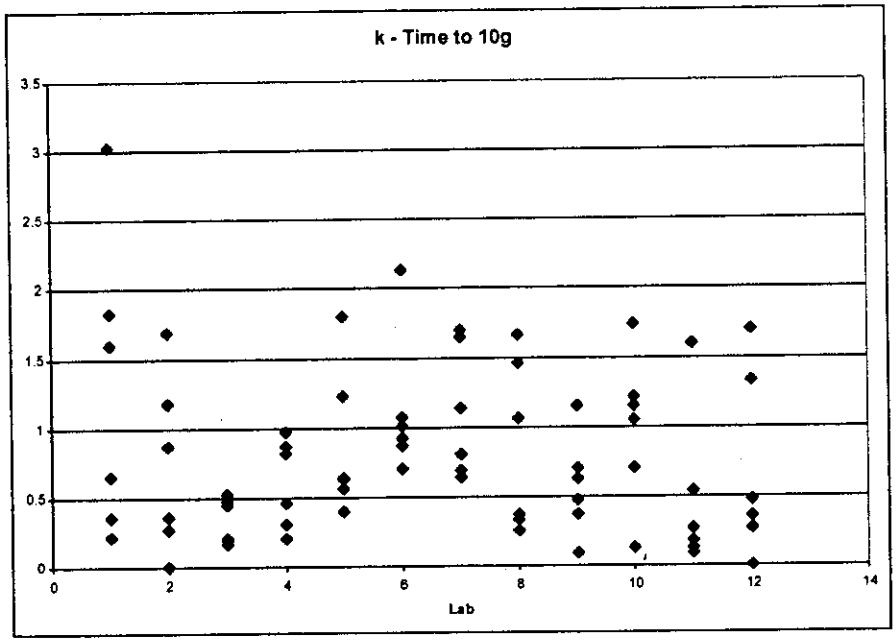


Figure 9. k values for t_{10}.

ASTM E691 provides a "critical" upper limit on k. For 12 labs and 3 replicates, the value is 2.14. The k value for one sample was far beyond this value and warrants re-examination (Table 11, Lab 1, Series 2). A second value (Lab 6, Series 5) was on the borderline. The graph of these k values is presented in Figure 9. Examination of this graph should point out certain differences in the patterns of k values by different labs. For

example, all of the points for Lab 3 are approximately 0.5 or lower, which suggests good repeatability (lower variation) for t_{10}. Other labs generally had higher k values, but only Lab 6 (Series 5) and Lab 1 (Series 2) had values at or above 2.14.

Table 12. h values for t_{10}, by lab

Lab	1	2	3	4	5	7
1	0.08	-1.24	0.35	0.17	-0.29	-0.56
2	0.55	0.08	0.43	0.37	0.83	-0.49
3	-0.43	-0.20	0.45	0.54	-0.10	0.38
4	-1.17	-0.45	0.00	-1.50	-1.99	-1.05
5	0.40	-0.34	-2.84	-0.63	1.01	-0.61
6	0.68	-0.34	0.00	-0.81	0.81	-1.02
7	-0.48	-0.55	-0.22	-0.76	-0.38	-0.76
8	-1.17	-0.34	-0.14	-0.15	-0.87	-0.90
9	-0.40	-0.02	0.49	-0.63	0.27	1.27
10	-0.80	0.12	0.42	1.77	-1.24	1.00
11	0.29	2.89	-0.29	-0.11	0.72	1.36
12	2.45	0.40	1.36	1.76	1.25	1.39

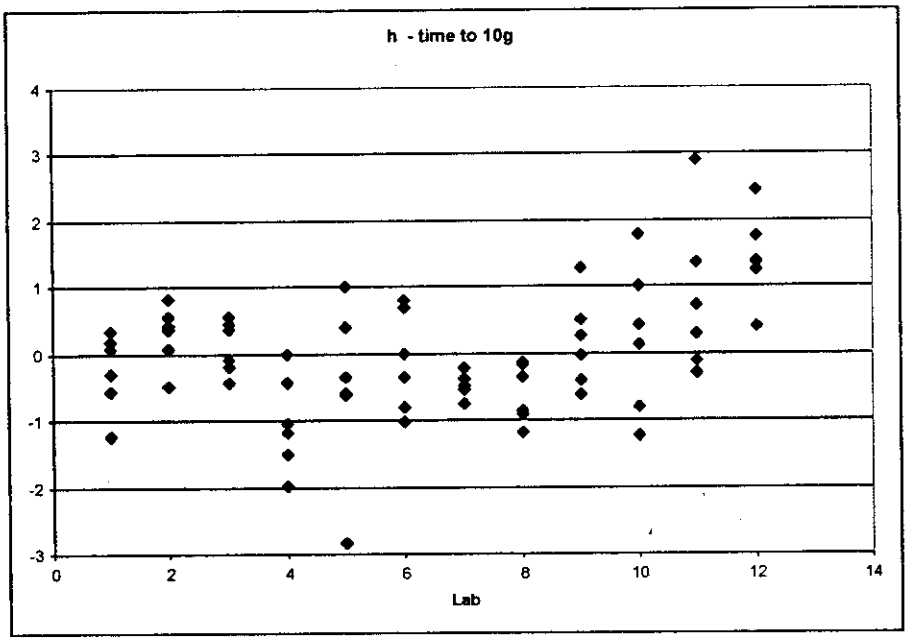


Figure 10. h values for t_{10}.

Table 12 and Figure 10 include all of the h values for t_{10}.

From Fig. 10, it can be seen that the laboratories' h values for t_{10} fell over a wide range. For example, Lab 12 was always above the average for all labs ("0"), while Labs 4, 7 and 8 were nearly always below the average for each Series of tests

Statistical Comparison of Laboratories

Although these tables and graphs are useful for general interpretation, an additional statistical measure is also available to assist in determining whether there are consistent differences among the laboratories.

The h values, representing differences in average level, will be examined first. For this measure, if the only differences among laboratories are due to random variation, then all the h's should vary with overall average of 0 and standard deviation of 1.0. This would be true for the individual laboratories as well. This would also result in the laboratory averages to be normally distributed with the same average 0, but standard deviation related to the number of samples (n = number of materials) tested. A statistic "z" is calculated as follows:

$$Z = \frac{(\bar{h} - 0)}{1/\sqrt{n}} \qquad \text{Eqn. 3}$$

where $\bar{h}$ is the average of the h's for a given lab. In this case n is 6 so the z value is simply $\bar{h} * \sqrt{6} = 2.45 * \bar{h}$.

Tables 13 and 14 show the z scores for each lab for $MLR_{20/40}$ and t_{10}, respectively.

Table 13. Avg. h and z for $MLR_{20/40}$

Lab	Avg. h	z
1	0.22	0.55
2	-0.13	-0.31
3	-0.02	-0.04
4	0.74	1.81
5	0.49	1.09
6	-0.55	-1.35
7	0.43	1.05
8	0.30	0.73
9	0.16	0.40
10	-0.05	-0.13
11	-0.76	-1.86
12	-0.75	-1.85

Since these "z" values would be expected to fall in a standard normal distribution, about 95% of the time the z should be between ±2.0. For the MLR's (Table 13), none of the overall averages appear to be unusual since none of the z's are beyond 2. However, a closer examination of the individual results reveals that Lab 11 has two high MLR sets (Series 2 and 4) which offsets the very low results on two other material results (Series 5

and 7). This permits an overall average h which is not statistically unusual. Further examination of this laboratory's tests would be warranted.

Table 14. Avg. h and z for t_{10}.

Lab	Avg. h	z
1	-0.25	-0.61
2	0.30	0.72
3	0.11	0.26
4	-1.03	-2.52
5	-0.50	-1.23
6	-0.11	-0.28
7	-0.53	-1.29
8	-0.60	-1.46
9	0.16	0.40
10	0.21	0.52
11	0.81	1.98
12	1.44	3.52

The z scores for t_{10} (Table 14) reveal that two labs are systematically very different from the others. Laboratory 12 had unusually high t_{10} values (longer time to start burning) and Lab 4 had unusually short times (started burning sooner). The results of these two labs would also heavily influence the subsequent value of reproducibility, since they were consistently far from the majority of the laboratory results.

Interpretation of the k values, using the z statistic, follows a similar approach as for the h values. However, the mean is not assumed to be zero or the standard deviations equal to 1.0. With samples consisting of 3 replicates and working with 12 labs, it can be shown that the mean k should be about 0.89. The standard deviation among the k's should be approximately 0.44. Since six k values are used in computing the average k, these averages should follow a normal distribution, with the result that a "z" score can be developed in a similar way to that done with the h values. In this case, the following equation applies:

$$z = \frac{(\bar{k} - 0.89)}{0.44/\sqrt{6}} \qquad \text{Eqn. 4}$$

In Tables 15 and 16, the approximate z values are computed for $MLR_{20/40}$ and t_{10}, respectively.

Table 15. Average k and z values for $MLR_{20/40}$.

Lab	Ave k	z
1	1.508	3.44
2	0.396	-2.75
3	0.362	-2.94
4	0.641	-1.39
5	0.632	-1.44
6	0.533	-1.99
7	0.958	0.38
8	1.101	1.18
9	0.726	-0.92
10	0.553	-1.87
11	0.157	-4.08
12	0.443	-2.49

When interpreting the z scores for standard deviation it is important to realize that when the z value is positive (greater than zero) it represents a typical repeatability greater than the average (assumed to be theoretically at 0.89). Values of z greater than plus or minus 1.96 only occur about 5% of the time, and more than 2.58 less than 1% of the time. Thus, the Lab 1 value of +3.44 for z (Table 15, MLR) is very high and indicates the repeatability standard deviations for this lab are much higher than would be expected (implying the repeatability is poorer).

Table 16. Average k and z values for t_{10}.

Lab	Mean k	z
1	1.280	2.17
2	0.728	-0.90
3	0.334	-3.09
4	0.606	-1.58
5	0.875	-0.08
6	1.116	1.26
7	1.101	1.18
8	0.855	-0.19
9	0.568	-1.79
10	0.995	0.59
11	0.466	-2.36
12	0.687	-1.13

When the z score is negative, then that lab has demonstrated much smaller standard deviations, which is an indicator of better repeatability. Labs 2, 3, 11 and 12 are examples of this (it is possible that one significantly high value of standard deviation might cause the overall repeatability standard deviations to be affected).

LARGE SCALE AND FULL SCALE TESTS

Preparation of Specimens

Large scale (LS) and full scale (FS) specimens for Series 2, 3, 4 and 7 were constructed of the same component materials as the small scale (ILS) specimens. However, the different size specimens were not identical with respect to the actual cushion construction and the juxtaposition of the seat and back. In the laboratory scale (ILS) specimens, the fabric side of the "back cushion" of the specimen butted up against the back of the "seat cushion." Thus, the seat was in front of the back in this configuration. In the LS cushion specimens, the seat cushion extended underneath the back cushion (or, conversely, the back cushion rested on top of the seat cushion). In the FS chair specimens, the seat butted up against the back, similar to the ILS configuration. It is uncertain whether or not these differences influenced the burning process. In all cases, the igniter was placed at the junction of the seat and the back. Generally, the vertical surface (the back) was the first to start burning; however, when burning extended downward into the seat, the different configurations could become more important.

The full scale specimens also had arms, whereas none were present for either the LS or ILS specimens. Arms could have an influence on the airflow in and around the junction of the seat and back, where the igniter was placed. More importantly, the vertical portion of an arm at the intersection of the seat and arm (and the corner configuration of seat, back and arm) could cause more rapid burning when flames reach that intersection.

The full scale chairs and large scale cushions were constructed using common, commercial production techniques. The polyurethane foam pieces for the back and seat cushions of the FS chairs were approximately three inches thick, while those for the LS cushions were four inches thick plus the batting. One half-inch thick polyurethane foam was wrapped on the inside, top and front of the arms (FS specimens only). The full scale chair seat cushion had a double thickness (two inches) of polyester batting on the top, front and underside of the cushion, but not on the sides or back. The back cushion had a single layer of batting (one inch) on the front and sides, but not on the back. There was no batting on the arms. The large scale cushions were also wrapped with polyester batting on the top, front and bottom of each cushion. The back edge of the LS seat cushion was the zippered side. There was no batting on the sides of the LS cushions.

The FR interliner was wrapped, in a double upholstery technique, around all six sides of the seat cushion and was sewn with Kevlar thread, for both LS and FS specimens. The interliner was located on all surfaces of the back cushion, except the back side. The interliner was wrapped on the inside, front and top, but not the outside, of each of the arms in the chairs.

LS & FS Test Results

The laboratory-scale results in this test method depended on measurement of mass loss vs. time. This scientifically accurate, physical phenomenon was recorded simply and accurately by the twelve laboratories. Mass loss rate (MLR), which is calculated directly

from mass loss-time measurements, represents the "mass burning rate" of the item. The following quote from reference 6 helps to put this calculation into perspective: "The burning rate of a fire source in a room is one of the key factors which describe the burning behavior. The radiant heat flux, the flame height, the smoke generation, etc., can be considered as a function of the mass burning rate." The author goes on to describe an engineering model of the mass burning rate of full-size upholstered chairs.

Either mass burning rate (i.e., MLR) or heat release rate may be used to characterize the relative fire hazard of a burning object, although use of HRR is much more widespread (e.g., see reference 7, p. 351; reference 8, pages 531-532; reference 9, section 1.5; and reference 10). In the larger scale tests, HRR was the primary measured parameter. Mass loss rate (MLR) for any given material is related to heat release rate (HRR) in accordance with the following equations:

$$Hc = \frac{HRR}{MLR} \text{ or } MLR * Hc = HRR, \qquad \text{Eqn. 5}$$

where Hc is the effective heat of combustion of the specimen. Heat release rate cannot be easily measured in this laboratory protocol because the specimens are too large for the common laboratory device used for such purposes (ASTM E1354, the cone calorimeter) and too small (i.e., HRR too low) for accurate measurement using one of the larger-scale HRR exhaust hoods (e.g., ASTM E1537/Cal T. B. 133). The heats of combustion are not the same for all of the component materials used in this test method (i.e., the various fabrics, battings and foams). However, with appropriate comparisons to larger scale composites, laboratory measurement of MLR may be suitable for developing assessments of relative fire performance of furniture mock-ups.

The effective heat of combustion, Hc in eqn. 5, is not expected to be the same for all materials in a class (e.g., fabrics), nor for all components in a composite specimen (e.g., fabrics, batting and foam). Thus, one could not, with any degree of accuracy, predict HRR of a burning composite specimen from the MLR alone (e.g., see reference 7, page 50; and reference 8, page 333). This does not change the fact that, for any given period in a fire experiment the MLR and the HRR are related by a proportionality constant (as supported by these same references).

An example of a good relationship of HRR and MLR as functions of time for one of the large scale tests is shown in Figure 11 (HRR plotted as a solid line, MLR plotted as a dashed line). The overall relationship between the two curves is apparent. It remains to be seen whether or not some estimated conversion factor (i.e., an "average" Hc) could be used for the entire span of any given test.

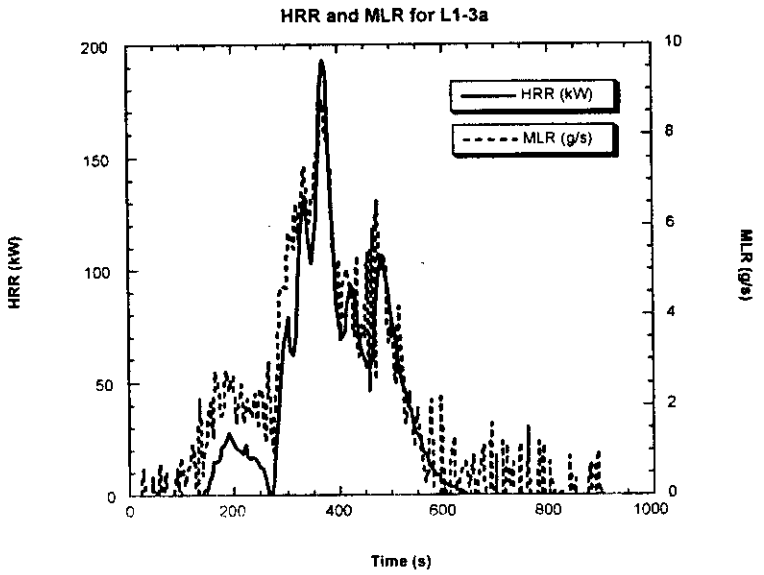


Figure 11. Plot of relationship of heat release rate (HRR) to mass loss rate (MLR) for a selected large-scale specimen.

As described previously, two "test results" were selected for comprehensive analysis of repeatability and reproducibility, average mass loss rate over the period from 20 g mass loss to 40 g mass loss ($MLR_{20/40}$) and time to 10 g mass loss (t_{10}). Although these might not be the ultimate test results, these two parameters reasonably represent the output of the test protocol. Statistical evaluation of other parameters would probably result in similar conclusions to those reached herein. Furthermore, if the physical aspects of the laboratory method do not change substantially (e.g., specimen setup, igniter intensity, application time), other "test results" could be computed at any time from these ILS results and subjected to their own statistical evaluation.

"Large-scale" and "full-scale" experiments were conducted on four composites by two laboratories in accordance with the design shown in Table 17. The large scale (LS) test specimens consisted of CA TB 133 mock-up cushions (back and seat) in that test method's mock-up frame, using the same small open flame ignition source used for the laboratory tests. The cushions were prepared with the same components as prescribed for the ILS specimens (Table 2). The full scale (FS) tests were conducted on full-size upholstered chairs ("lounge" style), constructed of the same components as for the lab and LS specimens. Certain features of the large-scale cushions and of the full-size chairs were necessarily different from that of the ILS specimens (this subject is discussed below).

Table 17. Large-scale (LS) and full-scale (FS) experiments, number of tests conducted

Series	LS1	LS2	FS1	FS2
2	3	3	3	----
3	3	3	3	3
4	3	3	3	----
7	3	3	3	----

Small Scale–Large Scale Comparisons

It proved to be somewhat difficult to compare the small scale (SS) and large scale (LS) results because the SS tests were terminated after 40 – 60 g mass loss; whereas the LS tests often proceeded to hundreds or even thousands of grams. It was decided to calculate and compare the average mass loss rate results for the same 20-40 g ML range as was done for the ILS data. Table 18 contains a summary of these results, as average values of three experiments for each Series and for the number of labs that reported results (twelve SS labs and two LS labs).

A plot of the LS and SS results from Table 18 is shown in Figure 12. An approximately linear relationship between the two sets of values is apparent. On the other hand, it should be cautioned that this is only one calculated result abstracted from the LS and SS data. A generalized relationship between results of these two sizes of specimens should not be derived from these results.

Table 18. Average $MLR_{20/40}$ results for large scale (LS) and small scale (SS) experiments

Series	LS[1] (g/s)	SS[2] (g/s)
2	1.23	0.90
3	0.72	0.52
4	0.27	0.16
7	0.62	0.44

Notes:

1) LS results are average of 2 labs

2) SS results are average of 12 labs

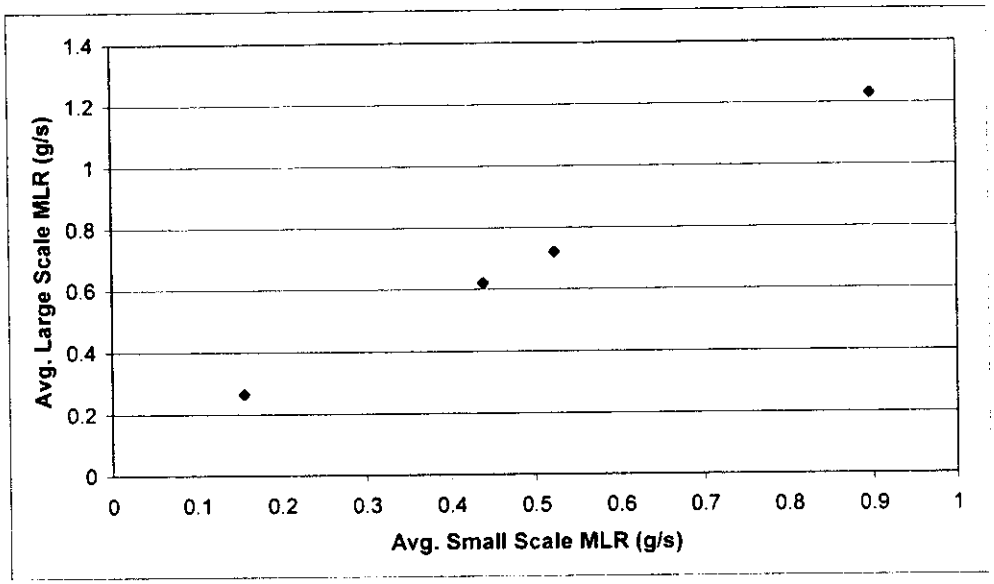


Figure 12. Average large scale $MLR_{20/40}$ results vs. average small scale $MLR_{20/40}$ results

Large Scale and Full Scale HRR Results

Typical HRR results for the LS and FS tests are shown in Figures 13 and 14, respectively.

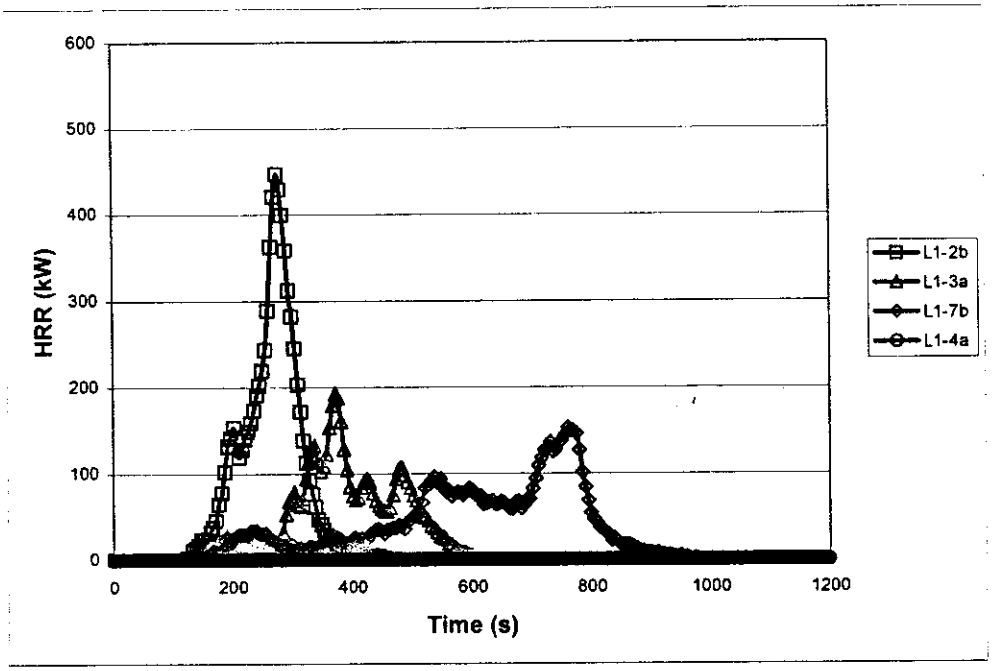


Figure 13. Selected plots of large scale HRR test results on different constructions (Series 2, 3, 4 and 7)

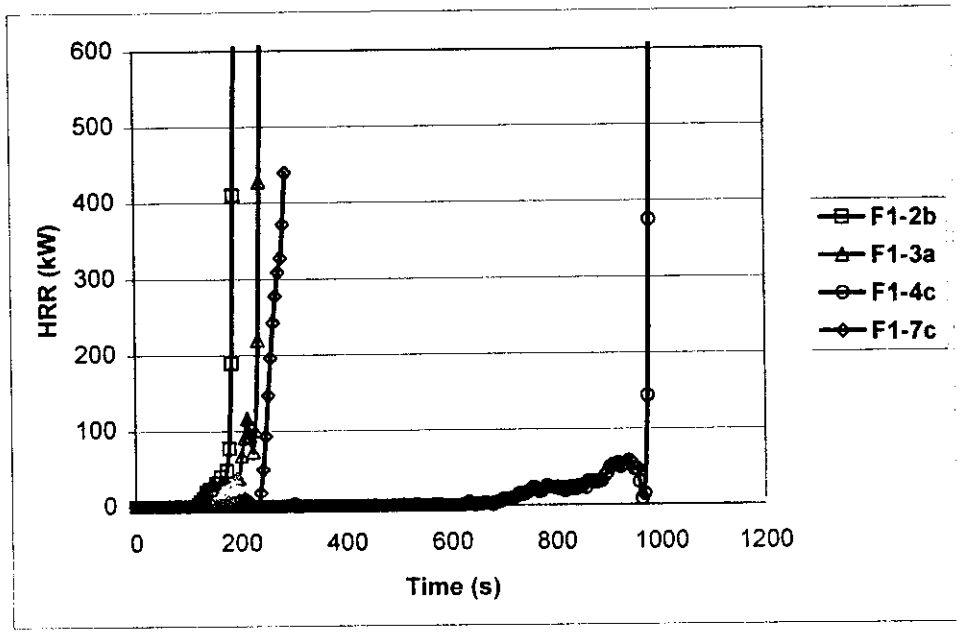


Figure 14. Selected plots of full scale HRR test results on different constructions (Series 2, 3, 4 and 7)

Suitable mass measurements for the full scale tests (as were obtained for the large scale ones) were not possible due to the larger variations, at low mass loss levels, in the load cells used for the heavier furniture items. Thus, comparison of the large scale and full scale results were done using heat release rate.

Four sets of composite specimens (Series Nos. 2, 3, 4 and 7) were subjected to the same small open flame ignition source as for the ILS. No "test result," as determined for the ILS, was established for the LS and FS results because statistical assessments were not performed on the larger scale results. In other HRR test methods, the results may take many forms, such as the following: peak HRR, time to peak HRR, avg. HRR over some time period, total heat release for the entire test (area under the HRR-time curve), time to ignition (or to some measurable HRR value), and others. With so many parameters to choose from, it was not practical to define a unique test result for the LS and FS tests in this program. Examination of the overall HRR-time curves for typical tests should be sufficient for comparison of the rank-order of ILS results to that for the larger scale tests.

The general presumptions regarding HRR-time relationships are that lower HRR, especially at the peak, generally corresponds to better fire performance and a lower fire hazard. Similarly, longer time to reach any given HRR, such as the peak HRR, also generally corresponds to better fire performance and a lower fire hazard. When both time and HRR are relatively higher or lower for one composition relative to another, the case for greater or lesser hazard is even stronger (within the limits of repeatability of the test).

HRR and time to reach some given HRR are analogous to the ILS calculations of $MLR_{20/40}$ and t_{10}.

The results of four, selected large scale (LS) tests are shown in Figure 13. Each selected curve was intended to be a typical or the most representative curve from the set of results obtained (HRR-time results for all of the LS and FS tests are included in Appendix C). From the plots in Figure 13, it is apparent that the Series 2 specimen had a poorer "fire performance" than the others because it produced a higher peak HRR at an earlier time. This ranking is consistent with the laboratory results for this composite. The Series 3 and 7 specimens in the LS experiments were slower to start burning than the Series 2 example, and they had lower peak HRR values than Series 2. This somewhat "better" fire performance than Series 2 is also consistent with the laboratory results (lower $MLR_{20/40}$ than Series 2 and longer t_{10} values). The Series 4 specimen did not ignite or produce any heat in all but a few of the LS tests (when it did ignite, the HRR never reached 20 kW, approximately the size of the CA TB 133 igniter). In all of the LS experiments, Specimen 4 was superior to the other three. In the laboratory-scale tests considered in this study, Series 4 tests produced the lowest $MLR_{20/40}$ results and among the highest t_{10} values.

From the results in Figure 13, it appears that the Series 7 specimen might be somewhat "better" than the Series 3 specimen in the LS tests because the time to achieve any substantial HRR was longer (e.g., about 200 s longer to achieve 50 kW HRR). Even with the variation observed in the LS results for the two sets of specimens (Appendix C), the Series 7 specimens still had the advantage of delayed time to involvement, compared to Series 3.

Taking into account the laboratory and large scale results, prior to discussing the full scale results, the "order" in which these four test specimens might be ranked in terms of relative fire performance would be as follows (from best to worst): Series 4, Series 7, Series 3 and Series 2.

Full Scale Test Results

All but a few of the full scale tests were extinguished prior to their achieving their maximum, or peak, HRR value. Generally, the tests were terminated between 400 and 800 kW in order to minimize damage to the test facility or hazard to the operators. Experience has proven that an item with sufficient fuel that exceeds 400 kW is not likely to stop burning of its own accord (the full scale furniture tests in this program that were allowed to continue burning all exceeded 1200 kW, and one test exceeded 2000 kW).

Selected full scale (FS) test results are shown in Figure 14. As for the LS tests, each plot was chosen to be typical of the tests conducted for the particular composite. All HRR results are contained in Appendix C. The "order" in which the specimens began to seriously increase in HRR, as shown in this figure, appeared to be the same as for the large scale results shown in the previous figure. Thus, the Series 2 specimen had the shortest time to any given HRR (poorest fire performance of the group tested) , followed

by Series 3, 7, and then 4. In these full scale tests, the Series 4 specimen eventually "took off" and burned like the other chairs, something that was not predicted in either the laboratory or the large scale results. The increased burning for Series 4 occurred more than 900 seconds (15 minutes) following ignition, with an upper range for the three replicate experiments of more than 1000 s (to reach 200 kW). The other three specimens (Series 2, 3 and 7) began to burn rapidly around 200s, less than 4 minutes. Further study of the reasons that the Series 4 chair specimens eventually burned is incomplete. The construction techniques used could have affected the result.

While there appear to be differences in the times to achieve a heat release rate of, say, 200 kW among the Series 2, 3 and 7 in Figure 14; it should be remembered that these plots are individual results of single experiments. The variability among the plots of replicate tests (Appendix C) make it unlikely that there is any significant difference among the FS results for these three compositions.

The Series 4 specimens (same fabric as Series 2 and 3, but with an interliner) were clearly the best of the four compositions tested in the LS and FS tests. These specimens were better than the others on the basis of mass loss in both the SS and LS experiments, and better HRR and/or time to full involvement in the LS and FS experiments. The other specimens included one with conventional batting and no interliner (Series 2), one with the new California-compliant batting (Series 3), and one with a heavy polyolefin fabric over an interliner (Series 7). It could be argued that none of these three compositions was significantly better than any of the others, when considering all of the laboratory, large scale and full scale tests.

Series 7 was an interesting case. This composition appeared to be somewhat better (although possibly not "significantly better") than Series 2 or 3 in the SS and LS tests. In the large scale test configuration, these specimens burned slowly at first, then eventually broke through the barrier after about 700 s. In the full scale tests, the Series 7 specimens were only marginally better than either the Series 2 or 3 specimens. In fact, one of the FS specimens became completely involved in fire (e.g., 400 kW) in as little as 230 s.

The Series 7 specimens were examples of a composite that behaved differently than would have been predicted by consideration of component testing alone. With an interliner and a California TB 117 foam, one might not have predicted this to burn as it did in the full scale test. In this case, the burning of the heavy weight fabric apparently overwhelmed the protective effects of the fire retardant barrier and the foam.

ALTERNATIVE DATA HANDLING

Examination of the data for mass loss (ML) versus time (t) indicated that the mass loss closely follows a function of the type:

$$ML = a * t^b, \qquad \text{Eqn 6}$$

where "a" and "b" are constants for any given set of data.

Taking the log of both sides, the equation is the following form:

$$\text{Log}(ML) = b*\log(t) + \log(a), \qquad \text{Eqn 7}$$

Where "b" is now the slope of the straight line on a log-log plot and "log a" is the intercept. These equations represent a "power curve" which has been used to describe exponential burning of real specimens in other fire experiments.

The values of "b" obtained by this analysis may provide useful information on the fire performance of the specimens. Values for these tests ranged from about 1.5 for Series 4 specimens, which burned relatively slowly, to about 3 for specimens which burned more rapidly.

The values of "a" or "log a" were extremely small, but provided an intercept value that could be used in further calculations. For example, this function (Eqn. 7) was used to make predictions of mass loss values at times beyond the range of most of the small-scale experiments (e.g., 300 seconds). In addition, the derivative of this function provided the means to calculate an instantaneous value of mass loss rate (MLR) at any selected time or mass loss point, compared to the "average" MLR determined over the range of 20 to 40 g mass loss that was used in the statistical compilation of the ILS results.

These calculations, while appearing to be somewhat more complex than the $MLR_{20/40}$ and t_{10} calculations used for the ILS results, can be performed using a standard spreadsheet program on a personal computer or using a basic scientific calculator that has log functions. An advantage of this procedure for handling data is that the calculation of the test result takes into account all of the "observations" (i.e., mass-time data) for the duration of the test.

DISCUSSION

An Inter-Laboratory Study (ILS) was successfully conducted on a small, open-flame flammability test for upholstered furniture mock-ups. Twelve laboratories participated in the ILS, testing seven different products in triplicate experiments. The test protocol, defined ahead of time, was followed with few exceptions. Laboratories submitted results in the form of mass and mass loss vs. time. Average mass loss rate (MLR) was calculated by the laboratories for a series of 10-g mass loss increments over the duration of the experiment.

Following the submission of the laboratory data, two "test results" were selected for application of the statistical treatment. These test results were quantifiable descriptions of the fire performance of the specimens under this test protocol. Average mass loss rate (MLR) over the range of 20 g mass loss to 40 g mass loss ($MLR_{20/40}$) was selected as the primary test result. The time to 10 g mass loss was selected as a useful additional measurement. One of the advantages of this test method, and of the protocol for data compilation, is that other "test results" can be developed from the same raw data, without requiring retesting. The two test results selected for this analysis are examples of ones that seemed to fit the nature of the test specimens.

This small open flame furniture test method has been demonstrated in these experiments to be suitable for a wide range of composite specimens, ranging from one that did not ignite to ones that ignited and burned readily. While it is difficult to compare the repeatability and reproducibility information with that of other fire tests, due to different ways in which test results are computed, it seems that the statistical results of this test method are within the range of variability of what one would expect for a "fire test method."

Of the six compositions that ignited and burned (i.e., all but Series 6), the Series 4 specimens had the lowest value of $MLR_{20/40}$, with an overall average of 0.16 g/s. This series also had the best repeatability (within laboratory) and reproducibility (between laboratories) standard deviations (i.e., variability). Expressed as the average value $\pm 2s_r$ (two times the repeatability standard deviation, which would be expected to encompass 95 percent of a normal distribution of results), the Series 4 average MLR could be expressed as 0.16±0.02 g/s. This is excellent repeatability and permits this value to be different from its closest other "competitor" (Series 7, with an average $MLR_{20/40}$ of 0.44±0.1 g/s) by a significant amount. The results of the Series 4 tests suggest that even small changes in material compositions, in a specimen that performs as well as this one, possibly could be distinguished from one another using this test method. In addition, the reproducibility was quite good, which suggests that none of the laboratories produced results for Series 4 that were very different from the average of all laboratories.

The mass loss rates ($MLR_{20/40}$) for the five compositions other than Series 4 ranged from 0.44 to 0.90 g/s. The variability of these results were generally about ±0.2 g/s (two standard deviations). Both the average and the s.d. are substantially higher than the results for Series 4. These relationships are illustrated in Figure 15, where the average $MLR_{20/40}$ is shown, with the range of two s_r (standard deviation for repeatability). Clearly, the Series 4 composition is statistically different from the others. However, the results for the other four composites were not statistically different from one another at the 95 percent confidence level. Despite the fact that these composites appear to be distinct, based on their average MLR values, it would be difficult to say that any given result was "significantly" different from any of the others in this group.

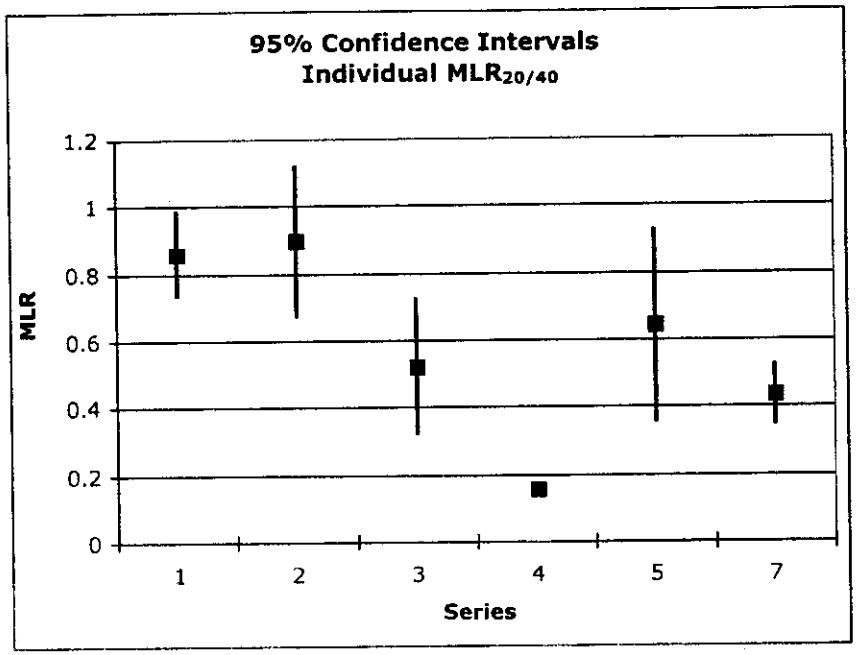


Figure 15. Average $MLR_{20/40}$ values for each Series, with ± 2 s_r

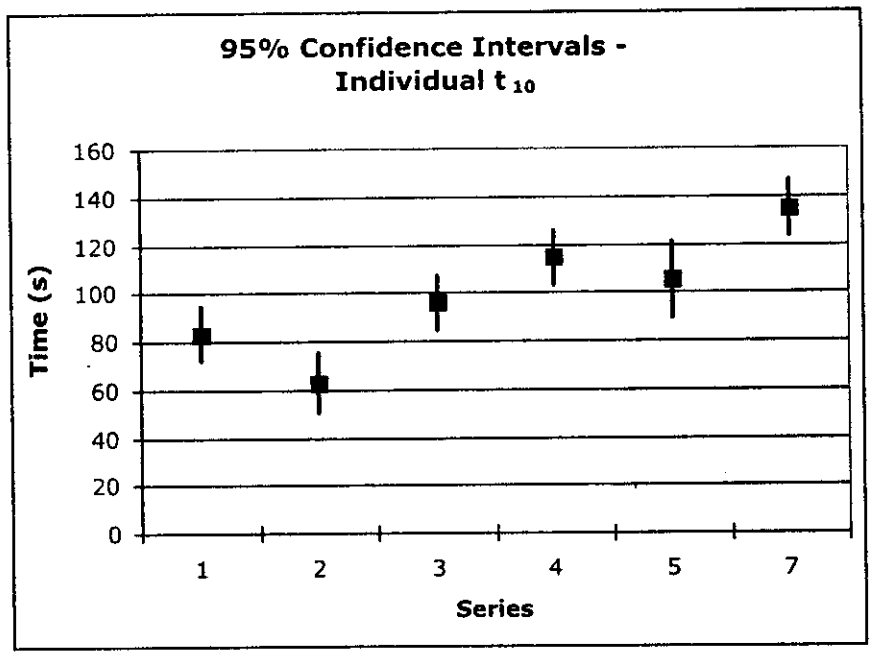


Figure 16. Average t_{10} values for each Series, with ± 2 s_r

All six compositions had similar levels of variation in the time to 10 g (t_{10}), around 6 seconds no matter what the average time was. This is reflected in Figure 16, where the lengths of the "bars" are nearly the same for all results. Here, a higher result is "better"

(longer time to the given mass loss), so Series 7 (rather than 4) is the best of the six results shown. This is somewhat misleading because Series 7 started out slowly, but picked up its MLR later on. In any event, the t_{10} results for Series 4 and 7 are not significantly different from Series 5 and Series 3. While it is believed that a "time to a given mass loss" is desirable, this parameter alone would be insufficient to differentiate among the better-performing specimens.

Some laboratories had consistently longer or shorter times than other labs, so the reproducibility numbers are relatively high. It seems that the "t_{10}" differences among laboratories tended to be systematic, i.e., one laboratory had consistently longer (or shorter) times to 10 g mass loss every time the test was performed. A better understanding of this phenomenon could permit adjustments in the final test protocol, such as inclusion of calibration tests, which might reduce the extent of these differences.

The estimates of precision, particularly the within-laboratory repeatability, can be used to assist in determining how well the test method would be capable of detecting differences from proposed specifications or regulatory requirements. This will depend on the selected number of replicates being averaged (i.e., the sample sizes).

Large scale cushion mock-ups and full scale furniture tests on four of the compositions from the ILS (Series 2, 3, 4 and 7) produced results comparable to the rank order of results from the laboratory scale tests. Thus, the "best" of these four laboratory compositions (Series 4) had the better performance in both the large and full scale experiments, while the "worst" composition of these four (Series 2) was also the poorer performer in the larger scale tests. The Series 4 composite in the laboratory testing proved to be an excellent performer in the "large scale" cushion tests, but did not perform as well as anticipated in the full size furniture tests, where it eventually burned. Even in the full scale tests, this composite was better than any of the other specimens tested.

The fire performance characteristics (based primarily on the ILS results, but with consideration of the larger scale tests when performed) of several of the composite specimens were significantly different from what was expected from component testing alone. For example, the Series 5 specimens (which contained BS 5852, crib 5 foam) did not perform substantially better than the Series 1 specimens (which contained CA TB 117 foam), even though the foam in Series 5 was more highly fire retarded. The Series 7 specimens (which contained a heavy polyolefin fabric) performed worse than the Series 4 specimens (which contained a rayon/polyester blend), even though both of these composites contained the same batting and interliner. The Series 3 specimens (which contained the new Cal. 117 batting) did perform somewhat better than Series 2 (conventional batting), but not as well as expected from component testing. Finally, it is apparent from the ignition response and the MLR-time progress of these experiments that the nature of the covering fabric has an important effect on the flammability of the overall composite (e.g., Series 6, with an FR-treated fabric did not ignite; and the lack of difference between the two FR foams may be due to the burning of the fabric). Based on

the results presented in this report, component testing alone may not be suitable for predicting the fire performance of composite products.

This test method has the capability of differentiating, on a laboratory scale, among the "better" and "poorer" real-scale fire performance of furniture items. This remains one of the major reasons for continuing to consider this test method for possible regulatory use. Even where a direct correlation between laboratory scale and full scale results could not be drawn, the relative performance ranking of specimens in the laboratory scale tests was maintained in the results of testing larger scale items.

CONCLUSIONS

The conclusions derived from this study may be summarized as follows:

1. The ILS on a small open flame (SOF) exposure of upholstered furniture mock-ups was completed successfully. Thus, twelve, very different laboratories were able to conduct the test procedure and to derive comparable results from the testing.
2. The statistical evaluation of the ILS results was more detailed and more in keeping with the precepts of ASTM E691 than probably any other fire test previously examined. The results of the statistical assessment ran the range from excellent "repeatability" (within laboratory) for some of the compositions to a lower order of repeatability for some of the other compositions (e.g., they ranged from a coefficient of variation of less than 10 percent of the average value to greater than 20 percent).
3. The reproducibility (between laboratories) encompassed a wide range (from less than 10 percent of the average value to more than 40 percent for one composition). Assessments of these variations and some rationale for the poorer reproducibility results were presented.
4. A major finding from the statistical assessment was that the Series 4 composite (with the "selected" fabric, an interliner, batting and foam), which ignited and burned at a slow rate, had a lower average mass loss rate ($MLR_{20/40}$) than the five other compositions that ignited, even taking into account the possible range in the average MLR values at the 95 percent confidence level.
5. One composition ("Series 6," which contained an FR-treated fabric) neither ignited nor lost any mass under this test protocol in any of the labs in triplicate tests. Although not dealt with in the statistical assessment (because there was "no result"), this composition represented an obviously good outcome for this test protocol. Thus, nearly the full range of possible results was demonstrated by these ILS tests, from a specimen that would not ignite to specimens that ignited and burned rapidly.
6. Based on the results presented in this report, component testing alone may not be suitable for predicting the fire performance of composite products. This statement is supported by the following observations: a) The use of a BS 5852 crib 5-compliant foam (Series 5) in place of a California T. B. 117 foam (Series 1) did not substantially improve the fire performance of the composite specimen; b) ignition of a heavy fabric was sufficient to cause an interliner to eventually break

through (Series 7 in the LS and FS tests); and c) the fire performance characteristics of the fabrics were of critical importance to the fire performance of the composite specimens in this test protocol (based on observations of all specimens).

7. The recording of mass loss and subsequent calculation of mass loss rate, which were accomplished without major problems and with some level of consistency, have the potential for use in a regulatory specification.
8. Large scale (California T. B. 133-size cushions in a mock-up) and full scale (actual upholstered furniture) specimens were tested, using the same ignition source as for the ILS. The large scale results were quantitatively comparable to the laboratory scale measurements, using the calculation of $MLR_{20/40}$; and the full scale results were qualitatively similar, using comparison of HRR, to the rank order of lab- and large-scale results. Additional tests should be performed to supplement those conducted in this program if a regulatory standard is pursued.
9. Mass loss rate is an accurately measured parameter that is relevant in fire hazard assessment of burning furniture items. The relative errors in the results, both in the laboratory scale and in larger scale experiments, should be taken into account if this method is considered for regulatory action.

RECOMMENDATIONS

An important aspect of an ILS is consideration of recommendations for improvements in the test protocol. The recommendations below were developed by the authors for changes in the test protocol, based on the results obtained during the ILS. These recommendations are offered to help improve the scientific validity of the test and, possibly, the repeatability and reproducibility of the method.

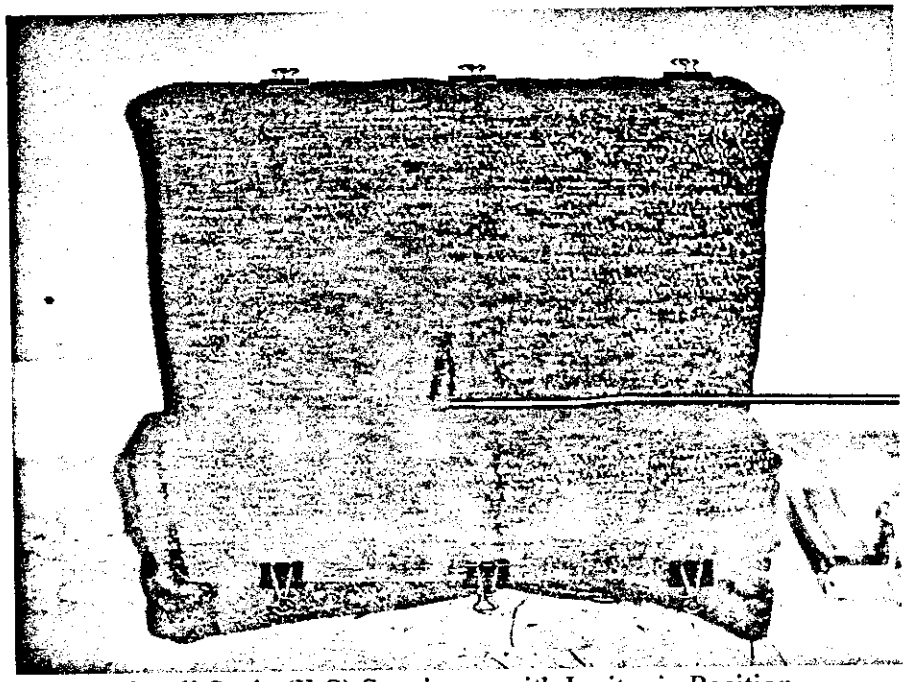
1. The method of installation of batting should be clarified (some of the laboratories wrapped the batting differently from the other labs).
2. Clear and unambiguous identification of all of the components of the furniture mock-up is imperative (e.g., in these tests, the two battings looked very much alike and may have led to incorrect use in some specimens).
3. Further requirements should be developed to limit airflow in the vicinity of the igniter flame in position on the specimen. (While measurement of airflow was "specified," the results of the ILS suggest that spurious air movement could have been a factor in the early ignition period in some experiments. A simple, clear plastic baffle in front of the specimen is one possible improvement.)
4. Specifications for the end point of the test should be reconsidered (e.g., tests of specimens exhibiting "moderate" mass loss rates during a test could be continued to see whether or not the MLR increases to an unsatisfactory level).
5. A method for dealing with the rounding of interpolated times and other calculations should be specified (this was not consistent among all labs).

6. The technique for establishing the "initial mass" of the specimen should be clarified (the preferred method would be to weigh the final composite immediately before the start of the test–this was not done by all labs).
7. The start time and the recording of subsequent times and masses during the test method should be clarified and followed (as described in this report, two labs started their timing devices after removal of the igniter, rather than upon placing the igniter).

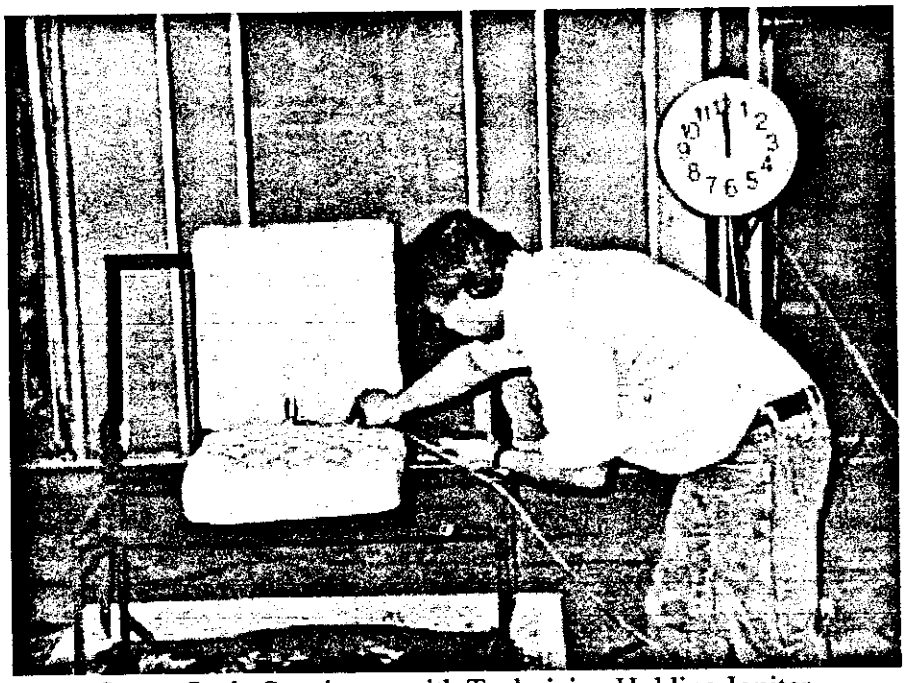
Additional laboratory experiments could include the following:

1. Evaluation of additional laboratory-scale specimens expected to produce low, moderate and high mass loss rates with consideration of error limits.
2. Testing of additional specimens that contain batting.
3. Development of a calibration technique or a "standard" specimen for laboratory use prior to running test specimens.
4. Evaluation of a variety of different fabrics and consideration of appropriate substrates for fabric testing.
5. Conducting further large scale and/or full scale tests for comparison to laboratory-scale results.

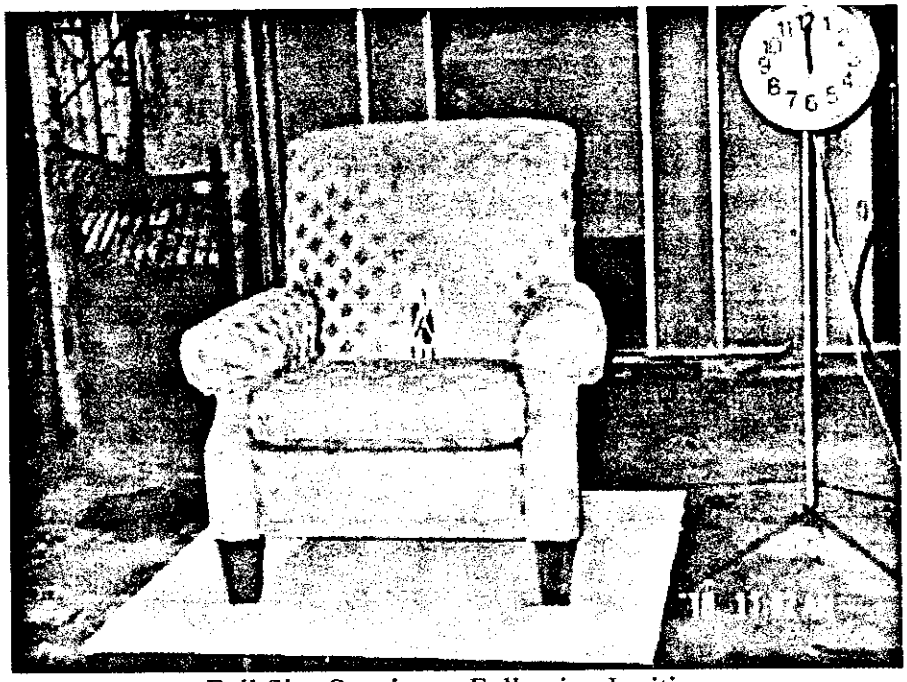
PHOTOGRAPHS OF CHAIRS



Small Scale (ILS) Specimen, with Igniter in Position



Large Scale Specimen, with Technician Holding Igniter



Full Size Specimen, Following Ignition

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ACKNOWLEDGEMENTS

The authors are indebted to the API and to the API Flexible Foam Combustibility Subcommittee for their direction, technical commentary and financial support. In particular, we acknowledge the technical contributions of Kurt Reimann, chairman of the subcommittee, and of Richard Skorpenske and Brian Fogg. The authors also acknowledge the contributions of the twelve laboratories who participated in the ILS, without whom we could not have developed this report.

APPENDIX A
API ILS REPORT (JANUARY 2004)
ILS TEST DOCUMENTS AND PROTOCOL; FINAL VERSION– AUGUST 22, 2002

Following is a compilation of the various documents sent by API to the test laboratories on or about August 22, 2002, prior to the start of the Inter-Laboratory Study (ILS). This includes the following documents that were previously separate from one another:

Note: Some formatting has been changed from the originals for sake of appearance and conformance to the original printouts of the documents.

August 22, 2002

To: ILS Laboratory Participants
From: Joel Mazelis, API ILS Coordinator
Subject: Preliminary Tests and Transmittal of Results

The Study Director for the API Interlaboratory Study is Kurt Reimann (734-324-6344, reimank@basf.com). Direct any technical or operational questions regarding the ILS to Kurt. The Study Coordinator is Joel Mazelis (703-741-5687, API, 1300 Wilson Blvd., Arlington VA 22209, Joel_Mazelis@americanchemistry.com). All lab data results must be forwarded to Joel.

Prior to conducting tests for the Interlaboratory Study (ILS), each laboratory must conduct two preliminary tests and submit the results to the API ILS Committee. This will help to satisfy the ILS requirement that all laboratories in the study be on an equal footing with respect to the particular test procedure. The Committee will review the results of the two preliminary tests and give either a "go ahead" or "check these items before testing" to each laboratory no later than 3 working days following receipt of the results.

The preliminary tests to be conducted are one each of "Series 1" and "Series 3," as defined in the document entitled, "Test IDs and Lab Results Sheet." Note that only one run need be conducted. There is no need to run "Series 1" in triplicate. All procedures called for in the "Test Procedure For API Furniture Interlaboratory Study; Final – August 21, 2002" should be followed. The results should be submitted in accordance with instructions in these two documents. Label the tests "Series 1," "Prelim 1"; and "Series 3," "Prelim 1." If additional preliminary tests are submitted, label them Prelim 2, Prelim 3, etc., for each "series" (please explain why additional tests were necessary!). Also include a copy of the "Small Scale Open Flame Furniture ILS Laboratory Cover Page" for each batch of results sent in.

For each test, we will expect to receive the following:

1) Completed "results" sheet,
2) Results in an Excel data file (see notes below on transmittal),
3) Video tape of test(s).

An Excel data file must be prepared to contain the test data (see instructions in "Test IDs and Lab Results Sheet"). For the preliminary tests, please prepare one file for the two experiments. For subsequent tests, prepare one file for every "batch" of results submitted to API (for example, if all materials have not arrived, the results on those tested should be forwarded without waiting).

All files must be in Excel format, with the extension ".xls." Please name the file by your laboratory i.d. and date of submittal (e.g., "S1-082702.xls") You may forward the results by any of the following means:

1) 3.5 in. floppy disk (PC format)
2) CD (Mac or PC, it shouldn't matter)
3) E-mail attachment (Please identify yourself in the body of the e-mail or we might not open the attachment!).

If you submit results on floppy or CD, please be certain it is protected from damage during shipping.

List of ILS Participants

Company	Address
BASF Corporation	1609 Biddle Avenue Wyandotte, MI
Huntsman	2190 Executive Hills Blvd Auburn Hill, MI 48326
Bayer Polymers	3801 West Chester Pike Newtown Square, PA 19073 and *100 Bayer Road* Pittsburgh, PA 15205
Omega Point Laboratories, Inc.	16015 Shady Falls Road Elmendorf, TX 78112
DuPont – Spruance Plant	5401 Jefferson Highway, Spot 395 Richmond, VA 23234
Cotton Inc	6399 Weston Parkway Cary, NC 27513
California Bureau of Home Furnishings and Thermal Insulation	3485 Orange Grove Avenue North Highlands, CA 95660
Hickory Springs	235 2nd Avenue, NW P. O. Box 128 Hickory, NC 28603
Foamex International	1500 East Second St Eddystone, PA 19022
North Carolina Foam Industries	1515 Cater Street Mt. Airy, NC 27030
Future Foam, Inc.	1610 Avenue N Council Bluffs, IA 51501
Carpenter Company	2400 Jefferson Davis Hwy Richmond, VA 23234

August 21, 2002
To: Small Scale Open Flame Furniture ILS Lab Participants
From: API ILS Committee
Subject: Test IDs and Lab Results Sheet

All of the labs should now have received the materials for the Furniture Mock-up Open Flame Interlaboratory Study (ILS). Following are descriptions of 1) the labeling of the individual components for the required tests, 2) a table showing the combinations of those components for the tests, 3) notes on completing the "Results" sheets, 4) the "Laboratory Cover Page," and 5) the "Results" sheet (last page). The full laboratory procedure, based on the February 2002 draft of the California Technical Bulletin 117, has been supplied to you as a separate document.

The combinations of materials and the test matrix are shown below.

Component Labels

COMPONENTS	I. D.
Fabrics	
"Selected" fabric	A
FR back-coated	B
Heavy polyolefin	C
Foams	
Non FR	A
BS 5852, crib 5	B
New Cal. 117	C
Batting	
Conventional	B
New CA compliant	C
Interliner	
Commercial FR	I

Combinations of Components for ILS Tests*

Series No.	Fabric	Foam	Batting	Interliner
1	A	C	none	none
2	A	C	B	none
3	A	C	C	none
4	A	C	B	I
5	A	B	none	none
6	B	A	none	none
7	C	C	B	I

*These specifications are for the ILS (laboratory scale) tests only – larger scale (CA TB 133 mock-ups) and full-size furniture items are designed to be comparable to the lab tests, but in some cases have slightly different components.

Each laboratory will be assigned an alphanumeric designation to be linked to the results from that lab:
Small Scale Labs: **S1 through S12**
Large Scale Labs (TB 133 mock-up size): **L1 and L2**
Furniture Test Labs: **F1 and F2**

INSTRUCTIONS FOR COMPLETING COVER PAGE AND RESULTS SHEETS

1. The cover page should be filled in completely by each laboratory. Only a single page should be completed and returned with the results pages. The purpose of this page is to provide contact information for the ILS committee in case there are any questions regarding the results. Note: this is the only page on which the laboratory name should appear.

2. The "results" sheets are labeled "Small Scale Open Flame Furniture ILS Results." Fill out one sheet for each test.

3. The "laboratory identification code" will be a unique code supplied to each lab by the ILS director. The name of the laboratory must not be on the results sheets. Only the lab and the ILS director will know the laboratory identification.

4. Please complete all blanks on the results sheets for every test.

5. The test i.d. consists of the "Series Number" (1 – 7) and "Run Number" ("prelim" for any tests done in advance of the ILS testing; "a," "b" and "c" for the triplicate runs required, or d, e, etc. for any additional runs conducted).

6. Indicate any deviation from the test plan (e.g., "couldn't make the seat cushion flat, so we did _____"). Certainly, you should follow the test plan as closely as possible.

7. Make and record observations during and after the test of the items noted on the results sheet. We have not requested an ignition time because it is, in our experience, an unreliable number. However, the ending of the test should be recorded. "Post test notes" might include the appearance of the specimen, such as the extent of charring or anything else you think might be helpful to someone studying the results (especially note anything out of the ordinary for one test compared to its replicate tests).

8. As described in the test protocol, results must be obtained no less often than every 10 seconds, whether the data are recorded by computer, interpolated from a strip-chart recorder, or taken manually. The lab may take data more often (e.g., 5 or 6 s are common intervals).

9. The results must be submitted as a Microsoft Excel spreadsheet in the following format (please remove all other headings, superfluous rows and columns before sending us the spreadsheet, but retain your original data!). As for the results sheets, identify your computer file only by the Laboratory I.D. (S1 through S12).

Time (s)	1st test I. D. & Mass (g)	2nd test I. D. & Mass (g)	etc.

Test I. D.s will be 1-a, 1-b, etc., through 7-c; so head the mass columns 1-a Mass (g), 1-b Mass (g), etc. This will produce one time column and 21 data columns. If your time recording is not consistent from run to run, then submit your data as follows:

1st Test I.D. Time (s) 1st Test I.D. Mass (g) 2nd Test I. D. Time (s) 2nd Test I. D. Mass (g)

10. The summary table on the results sheet (below) must not take the place of recording more frequent data. On the summary sheet, report the times (to the nearest whole second), by interpolation if necessary, to the mass loss (ML) values listed in the table (i.e., 0, 10, 20, 30 g, etc.), then compute the mass loss rate (MLR) for each increment (i.e., for 0-10 g, 10-20 g, etc.) to the nearest 0.001 g/s. Below is an example of the calculations required in the summary table.

11. Be certain that the laboratory operator and the supervisor initial (no full names, please, on the results sheets) to verify that the results page is "official."

Example of mass loss and mass loss rate calculations.

Experimental Results for one run (continued on next page)

Time (s)	Mass (g)	Mass loss (g)
0	715.5	0
5	715.5	0
10	715.5	0
15	715.5	0
20	715.5	0
25	715.5	0
30	715.4	0.1
35	715.4	0.1
40	715.4	0.1
45	715.4	0.1
50	715.4	0.1
55	715.4	0.1
60	715.4	0.1
65	715.4	0.1
70	715.4	0.1
75	715.4	0.1
80	713.4	2.1
85	713	2.5
90	712.9	2.6
95	712.3	3.2
100	712.3	3.2
105	712.3	3.2

110	712.3	3.2
115	710.3	5.2
120	710.3	5.2
125	710.3	5.2
130	710.3	5.2
135	707.6	7.9
140	707.1	8.4
145	707.1	8.4
148.8		10
150	705	10.5
155	704.7	10.8
160	704.7	10.8
165	702.1	13.4
170	702.1	13.4
175	699.6	15.9
180	699.6	15.9
185	697.7	17.8
190	696.6	18.9
192.9		20
195	694.7	20.8
200	693.1	22.4
205	691.4	24.1
210	689.9	25.6
215	689.5	26
220	685.6	29.9
220.4		30
225	684.2	31.3
230	682.1	33.4
235	680.8	34.7
240	680.8	34.7
245	680.8	34.7
250	680.8	34.7
252.4		40
255	669.6	45.9
260	667.6	47.9

The interpolation of the times to 10, 20, 30 and 40 g mass loss are done using the generic equation given below:

$$\left[\frac{(m_x - m_1)}{(m_2 - m_1)} \times (t_2 - t_1)\right] + t_1 = t_x,$$

where m_1 is the mass loss reading just prior to the selected mass loss increment (e.g., 10.0 g), m_2 is the mass loss readings just after the selected mass loss increment, and m_x is the mass loss increment. The time readings, t_1 and t_2 correspond to m_1 and m_2 and tx is the

interpolated time. This is a standard interpolation of data between two x-y pairs, assuming linearity between neighboring points.

The data from the above list that correspond to m_x = 10 g are as follows:

$$\left[\frac{(10.0-8.4)}{(10.5-8.4)}\times(150-145)\right]+145=148.8,$$

which is 149 seconds, when rounded to the nearest second.

The remainder of the results from this example produce the results in the following "summary table." Please note the criteria in the test protocol for ending the test. Had this example test gone past 40 g, the results for 50 and 60 g, if available, would have been included in the summary. Labs should not continue past 40 g unless they feel they can do so safely.

Summary Table

Time (s)	ML (g)	MLR (g/s)
0	0	----
149	10	0.067
193	20	0.227
220	30	0.370
252	40	0.313

SMALL SCALE OPEN FLAME FURNITURE ILS LABORATORY COVER PAGE

(This is the only page on which the laboratory name should appear)

Laboratory Name _____

Address _____

Address _____

City, State, Zip _____

Phone _____ Fax _____

E-mail Contact: Name _____ e-mail _____

ILS Supervisor _____

ILS Test Operator(s) _____

SMALL SCALE OPEN FLAME FURNITURE ILS
RESULTS (ONE PAGE FOR EACH TEST)

Laboratory Identification Code (S1 through S13) _____

Date of Test _____ Approx. Test Start Time _____

Test Area: Temp. _____ °F / °C _____ % R. H.

Was specimen kept under controlled temperature/humidity prior to test? Yes / No

Test I. D. Series No. _____ Run No. (a, b, c, etc.) _____

COMPONENT	Included (Y / N)	I. D. of component	Weight of component (g)
Fabric		A B C	
Interliner		I	
Batting		B C	
Foam		A B C	

Any deviation from test plan in specimen preparation? Yes / No

If Yes, explain: _____

Observations During Test		Run Time (min:sec)
Flaming combustion after removal of ignition burner?	Y / N	----------
Specimen Self extinguished?	Y / N	
Experiment stopped	-------	

Other observations _____

Video taken? Y / N **Burn through back**? Y / N **Burn through seat**? Y / N

Post-Test Notes: _____

RESULTS: See attached instructions regarding submittal of data and completion of the summary table below.

Time (s)	ML (g)	MLR (g/s)
0	0	
	10	
	20	
	30	
	40	
	50	
	60	

Initials (only) _____ _____ **Date** _____

Operator **Supervisor**

TEST PROCEDURE FOR API FURNITURE INTERLABORATORY STUDY

Final – August 21, 2002

This test protocol is based on the proposed California Technical Bulletin 117 (February 2002 Draft), with additions and changes specific to the API Inter-Laboratory Study (ILS). The additions and changes are noted with the heading "**ILS NOTE**" (the notes are numbered in this version of the document, for ease in referencing specific instructions). No changes have been made in the text as proposed by California and reprinted below (the California test also has "notes," designated simply by "NOTE.") A video tape has been sent to all ILS labs as an instructional tool and training sessions have been arranged. These will provide further information on cutting materials, assembling specimens and conducting the test in accordance with the procedures set out below. In addition, a separate document describes the details for completing the required "results" sheets.

Section 5 - Upholstered Furniture Composite Mock-up Test- Open-flame Resistance

5.1 Scope – If an upholstery fabric that does not meet the requirements of Part I, Section 1.A is intended for use in furniture, a composite mock-up assembly containing the actual filling materials shall pass this test to qualify the fabric for use in actual furniture. This composite test is designed to assess the tendency of a bench-scale mockup system to burn with a small open-flame. The mock-up consists of a seat and back piece constructed of the actual cover fabric (and any interliner (fire barrier) material, if present) and the filling materials in the first three inches of layering of the actual furniture item. The intent of this standard is to produce upholstered furniture which is generally safer from the hazards associated with small open-flame, by slowing the ignition and propagation rate of a fire and allowing additional time for occupant recognition and escape.

5.2 Summary of Test method - This test method is based on application of a small open-flame to the crevice of a seat/back mock-up specimen of a furniture composite assembly. The burning behavior of the specimen is observed. The continuous weight loss and time of burning of the specimen are recorded.

ILS NOTE 1: *In practice, the weight (mass) and time measurements are not continuous, but are taken at sufficient intervals to permit plots of mass and mass loss v. time.*

5.3 Significance and Use - This test method is designed to measure the response of a furniture composite mock-up assembly to a small open-flame ignition source representing a match, candle or cigarette lighter or similar size ignition source.

5.4 Test Apparatus and Materials - The test apparatus, including the furniture mock-up assembly frame, the gas train and accessories are described in Annex A.

5.5 Test Facility/Hazards - The test facility, exhaust system and hazards are described in Annex B.

5.6 Conditioning – Condition test specimens prior to the test for a minimum of 24 hours at 23 ± 5 °C (73 ± 9 °F) and 50 ± 10% RH. If the sample is taken from a finished article of furniture, conditioning does not begin until the component is removed from the furniture.

ILS NOTE 2: *For any laboratory that does not have a constant temperature/constant humidity room for conditioning specimens, temperature and humidity readings must be taken and recorded at least once daily in the area in which the specimens are stored.*

If conditions in the test area are not the same as in the conditioning area, tests should begin within 10 minutes of removal from conditioning area.

ILS NOTE 3: *Test shall begin within 10 minutes of removal from the conditioned area, if test room conditions are outside those required of the conditioning room.*

5.7 Test Specimens

ILS NOTE 4: *For the ILS, weigh the separate pieces used to assemble the composite specimen prior to each experiment.*

Cover Material and Flame-Resistant Interliner (if used)

The cover fabric size needed for each test is 1020 x 700 ± 10 mm (40 x 27.5 ± 0.4 in). The cover fabric specimens shall have triangular cut-outs 575 mm (22.5 in) from one end on both sides. The size of these cut-outs shall be approximately 55 x 135 ± 5 mm (2.1 x 5.25 ± 0.2 in) high. See Annex A, Figure A-2.

ILS NOTE 5: *The size of the triangular "cut-outs" shall be as indicated in this paragraph, not as illustrated in Annex A, Figure A-2, included herein. It is strongly advised that a template be prepared by each laboratory to assist in marking the fabric or interliner for cutting the outer dimensions and the cut-outs. The template should be prepared from some durable, rigid material (e.g., clear, thin PMMA).*

If an interliner (fire barrier) is used, cut it to the same dimensions and in the same orientation as the cover fabric, for fitting to the metal test frame under the cover.

If a furniture product contains more than one type of upholstery fabric, each type of fabric must be tested to the fabric open-flame component test (Part I, Section 1.A).

Composite Upholstery Filling Assemblies

Some cushioning assemblies consist of several layers, typically a fiber batting, wadding or pad over various foams. The upholstery fillings shall consist of the actual filling materials present in the first three inches of layering of the seat of the furniture item and the first three inches of layering of the back. Filling types should be placed in the same order in the composite mock-up as they are located in the actual furniture.

Use two separate assemblies of filling pieces, one for the vertical back and one for the horizontal seat. The vertical (back) pieces shall have total dimensions of 450 x 300 mm ± 5 mm (17.6 x 11.7 ± 0.2 in) x 75 ± 2 mm (2.9 ± 0.2 in) thick. The horizontal (seat) pieces shall have total dimensions of 450 x 75 ± 5 mm (17.6 x 2.9 in ± 0.2 in) x 75 ± 2 mm (2.9 ± 0.2 in) thick.

ILS NOTE 6: *The use of the term "filling pieces" in this document is not clear. For the purposes of the ILS, all of the foam pieces will be cut to the dimensions shown above (however, tolerances will be ±5 mm for all dimensions, not 2 mm). See below for additional information on batting.*

Note: Filling materials for use in this test are not subject to the dimension tolerances of fabrics and flame-resistant barrier fabrics since they are more difficult to cut to accurate sizes.

Where the total thickness exceeds 75 mm (3 in), reproduce only the upper 75 mm (3 in) of the cushioning assembly, except that the upper layer, typically fiber batting, is continued over and around the front edges of the seat assembly and the top edges of the back assembly. If the filling in either the seat or back of the actual furniture is less than 75 mm (3 in) thick, do not build up the test piece to a thickness of 3 inches but test at the thickness found in the actual product. Pull the fabric tight so that no air gap exists between the fabric and fill at any point.

ILS NOTE 7: *For the ILS, we will use the same size foam pieces for all tests, we will not trim the foam to accommodate batting. Place batting around the top, front and sides of the "seat" foam, but not on the back or bottom. Place batting on the front, both sides and the top of the "back" foam, but not on the bottom or back. The seat cushion will stick out from the frame by approximately one-half the thickness of the batting (e.g., 1/2 inch), corresponding to a 50 percent compression.*

Filling layers which are more than 3 inches below the upholstery fabric are not included in the construction of the composite assembly.

Conduct the composite test with loose filling components only if they are encased in a flame-resistant ticking/fabric and the cushion insert constructed with this fabric and filling has previously complied with Part I, Section 4. If the loose filling material in the actual furniture exceeds three inches in thickness, construct a three-inch thick cushion insert with the overall dimensions given above, at the filling density of actual use and place in appropriate location in the mockup (back or seat).

ILS NOTE 8: *We will not be dealing with loose filling components in any of these tests.*